

Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide

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Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide

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PREFACE

In September of 2006, the Applied Technology Council (ATC) was awarded a task entitled “Update of FEMA 74, Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide” (designated the ATC-69 Project) under its ongoing “Seismic and Multi-Hazard Technical Guidance Development and Support” contract (HSFEHQ-04-D-0621) with the Federal Emergency Management Agency (FEMA). The primary objective of this project is to update the third edition of the FEMA 74 report, *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide*, issued by FEMA in 1994.

FEMA 74 explains the sources of earthquake damage that can occur in nonstructural components and provides information on effective methods for reducing risk associated with nonstructural earthquake damage. It is intended for use by a non-engineer audience that includes building owners, facility managers, maintenance personnel, store or office managers, corporate or agency department heads, and homeowners. The reference material contained within the third edition of FEMA 74 is now approaching 20 years old. A considerable amount of new information now exists as a result of ongoing National Earthquake Hazard Reduction Program (NEHRP) activities, local and state government programs, private sector initiatives, and academic work focused on reducing the potential for nonstructural earthquake damage.

This fourth edition of the FEMA 74 document updates both the content and the format of the report. The document has been redesigned for use on the internet. Currently, the report contains seventy-two examples, complete with photos of actual damage and details illustrating correct mitigation measures. The new format makes it simple to browse and to print out the relevant details.

1. INTRODUCTION

This chapter of the document describes the purposes of this e-document and describes the intended audience for the e-document.

1.1 PURPOSE

Nonstructural failures have accounted for the majority of earthquake damage in several recent U.S. earthquakes. Thus, it is critical to raise awareness of potential nonstructural risks, the costly consequences of nonstructural failures, and the opportunities that exist to limit future losses. Nonstructural components of a building include all of those components that are not part of the structural system; that is, all of the architectural, mechanical, electrical, and plumbing systems, as well as furniture, fixtures, equipment, and contents. Windows, partitions, granite veneer, piping, ceilings, air conditioning ducts and equipment, elevators, computer and hospital equipment, file cabinets, and retail merchandise are all examples of nonstructural components that are vulnerable to earthquake damage. The primary purpose of this guide is to explain the sources of nonstructural earthquake damage and to describe methods for reducing the potential risks in simple terms.

1.2 INTENDED AUDIENCE

This guide is intended for use by a non-engineer audience located within the United States; this audience includes building owners, facility managers, maintenance personnel, store or office managers, corporate or agency department heads, business proprietors, risk managers, and safety personnel. The guide is also designed to be useful for design professionals, especially those who are not experienced with seismic protection of nonstructural components. It addresses nonstructural issues typically found in schools, office buildings, retail stores, hotels, data centers, hospitals, museums, and light manufacturing facilities. It is not intended as a guide for homeowners. How to make homes safer from earthquakes is covered in FEMA 232 *Homebuilders' Guide to Earthquake-Resistant Design and Construction* (2006). This document is also not intended to address nonstructural issues relevant to heavy manufacturing, specialized industrial manufacturing, or power generation facilities.

The guide is aimed at a wide audience with varying needs. Some readers may be small business owners with a limited number of potential problems, which could be addressed in a few days by

hiring someone to install some of the non-engineered or prescriptive details that are presented in Chapter 6 of this guide. Other readers may be responsible for hundreds of facilities and may need a survey methodology like the one described in Chapter 3, to help them understand the magnitude of their potential risk. For those who need to implement nonstructural details, the specification and responsibility matrices in Appendices A and B can be used to clarify the scope of work and assign parties responsible for implementation. The prospective audience can be subdivided into the following four general categories:

- General Interest—the non-engineer reader who wants an illustrated overview of the subject of nonstructural earthquake damage.
- Small Business Owner—the reader who wants a general overview of the subject, along with help in identifying potential risks and specific guidance on suggested protective measures that the reader can implement on his or her own. This may be all that is required for a small business or simple facility, if the items can be addressed using the non-engineered or prescriptive details shown in Chapter 6.
- Facilities and Planning Personnel—the reader who needs an overview of the subject, as well as a survey methodology that is applicable to an organizational setting. This guide contains forms and checklists that can be used to survey a facility, in order to identify potential risks and to estimate seismic vulnerability and potential earthquake losses. The guide includes suggestions for both existing and new construction and differentiates between methods that can be readily implemented by a handy worker following the non-engineered and prescriptive details in Chapter 6 and methods that require professional design assistance and additional engineered details.
- Architect or Engineer—the architect or engineer who has limited knowledge of nonstructural earthquake damage and who needs an introduction to the subject, along with a list of resources that will provide more detailed technical information. For this audience, the examples provided in Chapter 6 may serve as a starting point

General Interest Sidebar

This style of sidebar is used in this guide to provide additional clarification or examples for the general interest reader.

Technical Sidebar

This style of sidebar is used in this guide to provide additional technical details for architects and engineers.

or conceptual design for common conditions; calculations may be required to size members and connection hardware for each particular situation. The specification and responsibility matrices in Appendices A and B are targeted for this audience; these are tools intended to help clarify the scope of work and assign responsibility for the various tasks involved.

Table 1.2–1 below is intended to help readers identify those portions of the guide that may apply to their particular situation and interests. The chapters and their respective audiences are intended to be helpful, not restrictive. Readers are encouraged to use this guide and to adapt the forms and checklists herein in any way that is helpful to their particular circumstances. The flowchart on the following page provides some additional guidance on how to use this document. While earlier editions of FEMA 74 were aimed at a more general audience, the 4th edition has been greatly expanded to assist owners, facility managers, and design professionals implement nonstructural mitigation programs. A flowchart is also provided in Figure 1.2–1 to help readers identify portions of the guide that may apply to their situation.

Table 1.2–1 How to use this guide

Chapter Title	General Interest	Small Business Owner	Facilities and Planning Personnel	Architect or Engineer
Chapter 1. Introduction	X	X	X	X
Chapter 2. Behavior of Nonstructural Components	X	X	X	X
Chapter 3. Survey and Assessment Procedures for Existing Buildings		X	X	X
Chapter 4. Nonstructural Risk Reduction for Existing Buildings			X	X
Chapter 5. Nonstructural Risk Reduction for New Buildings			X	X
Chapter 6. Seismic Protection of Nonstructural Components	X	X	X	X
Appendix A. Specification				X
Appendix B. Responsibility Matrices				X
Appendix C. Survey Form		X	X	X
Appendix D. Checklist		X	X	X
Appendix E. Risk Ratings		X	X	X
Appendix F. Glossary	X	X	X	X

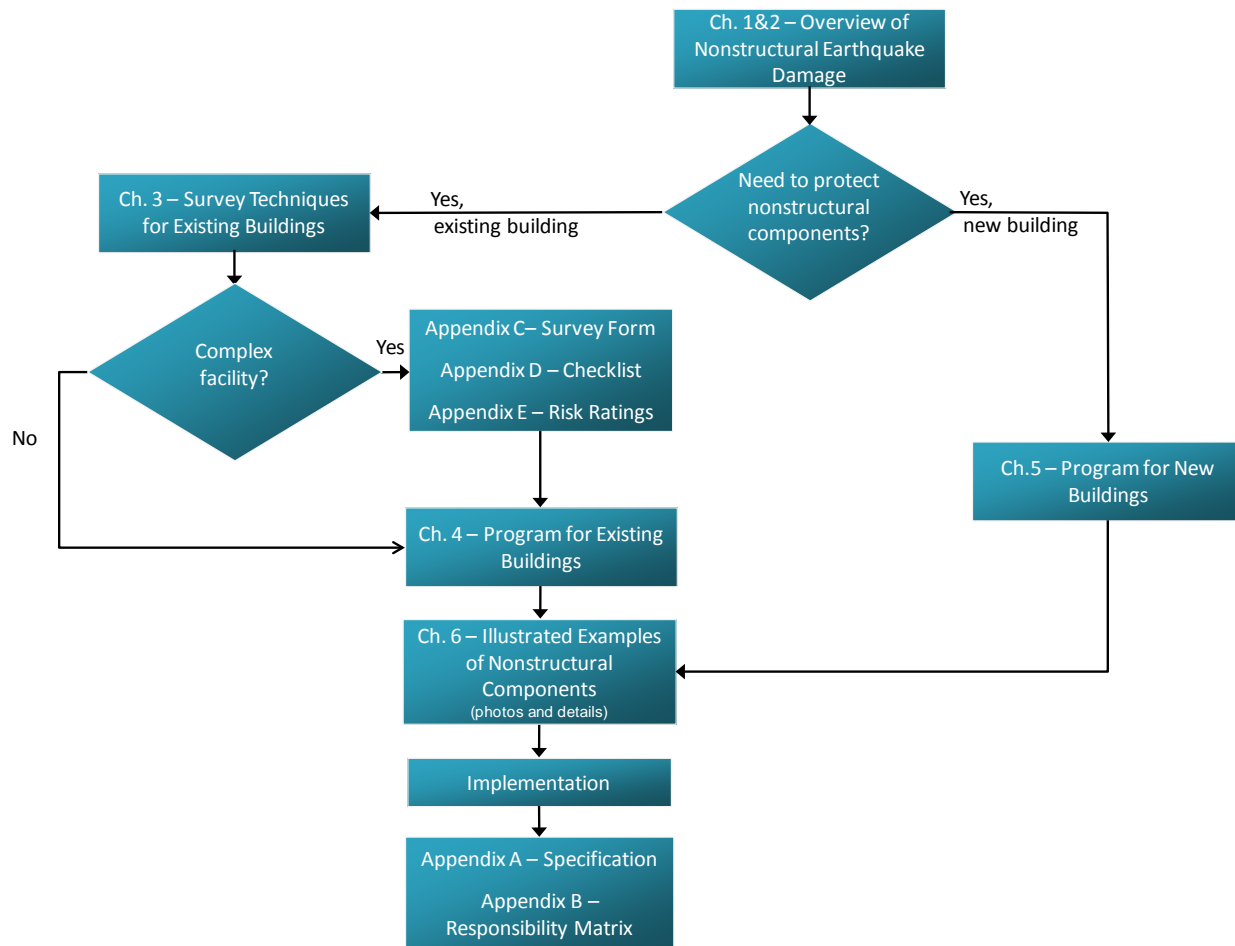


Figure 1.2–1 Flowchart describing the relationship of document chapters and appendices.

1.3 REGIONAL APPLICABILITY

Different geographic areas of the U.S. are likely to experience different levels of seismic shaking in future earthquakes. In conjunction with the Probable Shaking Intensity Map shown in Figure 3.2.1-1, the following considerations will help to determine if these guidelines are applicable to your facility:

- If the Shaking Intensity Map indicates that the building site is located in an area with minimal level of shaking, then the seismic hazard risk is extremely low and thus seismic anchorage and bracing of nonstructural components is not considered necessary.
- If the Shaking Intensity Map indicates that the building site is located in an area with low level of shaking and if the facility is not an essential type facility, then only parapets and exterior unreinforced masonry walls should be considered for seismic retrofit.
- If the Shaking Intensity Map indicates that the building site is located in an area denoted with moderate level of shaking, and if the facility is not an essential type facility, then only architectural components should be considered for seismic retrofit; anchorage and bracing for other nonstructural components may not be necessary.
- If the Shaking Intensity Map indicates that the building site is located in an area denoted with high level of shaking, then adequate retrofitting of all nonstructural component items should be considered.

Essential Facilities

Hospitals, fire, rescue, and police stations, emergency vehicle garages, and designated emergency shelters are examples of essential facilities that require special design considerations.

If in doubt about the applicability of these guidelines to a particular case, then it may be useful to check the requirements in ASCE/SEI 7-10 *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2009) for new construction. If the nonstructural component does not require bracing for new construction at the site, then it may not be necessary to brace this component in existing construction, pending consideration of the specific risks posed by potential damage.

1.4 LIMITATIONS

This guide advises users on how to identify nonstructural hazards and how to implement earthquake protection measures. Earthquake engineering expertise is often desirable when identifying and reducing earthquake risks, and in some situations, it is required. This guide attempts to provide advice regarding earthquake protection measures and presumes that the advice will be applied wisely, and that expert assistance will be obtained whenever necessary.

When in doubt about the seismic vulnerability of a facility, one should consult a civil or structural engineer or an architect with specific training and expertise related to the evaluation and mitigation of nonstructural earthquake hazards.

1.5 ACKNOWLEDGEMENTS

ATC gratefully acknowledges the ATC-69 Project Management Committee, including Maryann Phipps, Cynthia Perry, Robert Bachman, James Carlson, Eduardo Fierro, and Richard Kirchner for their efforts in researching and developing the material contained in this report. The Project Review Panel, consisting of Tim Brown, Mary Comerio, David Conover, Doug Fitts, Michael Griffin, John Henry, Robert Reitherman, and Jeffrey Soulages, provided technical review, advice and consultation at key stages of the work. In addition, Dawn Anderson, Jon Gregg, and Eric Peabody provided review comments for Appendices A and B. The affiliations of these individuals are provided in the list of project participants.

ATC also gratefully acknowledges Cathleen Carlisle and Mike Mahoney (FEMA Project Monitor) and Barry Welliver (Subject Matter Expert) for their input and guidance in the preparation of this

Limitations of the Non-engineered Approach

If this guide explained how a person could administer his or her own health exam, diagnose any health problems, and prescribe and administer appropriate treatment, then an obvious question would arise: How far can an untrained person proceed before requiring the services of a physician? While doctors commonly recommend many self-help measures, such as taking one's own temperature and treating minor colds with home remedies, it is important to recognize when one has exceeded the limits of commonsense measures and needs to seek the advice of a medical professional.

When in doubt about a health problem, consult a medical professional.

When in doubt about the "seismic health" of a facility, consult a civil or structural engineer or architect.

report, Ayse Hortacsu and Peter N. Mork for ATC report production services, Scott Hiner for the expert graphics, Thomas R. McLane as ATC Project Manager, and Steven Kuan as ATC Board Contact on this project.

2. BEHAVIOR OF NONSTRUCTURAL COMPONENTS

Effective seismic risk reduction strategies for nonstructural component damage begins by clearly understanding the scope and nature of nonstructural components in buildings, their behavior in earthquakes, and the consequences of damage. The next section will address the following key questions:

- What are nonstructural components?
- What are the primary causes of damage to nonstructural components during earthquakes?
- What is the significance of nonstructural component damage?
- Which nonstructural components are most vulnerable in an earthquake?
- What are the consequences of damage to nonstructural components?

A picture is worth a thousand words.

The Hyogo Earthquake Engineering Research Center in Japan has posted video footage of shake table testing of nonstructural components during a simulated earthquake. Two of these video clips speak volumes about the hazards of nonstructural components during an earthquake. The video clips focus on the behavior of furniture, contents, and some architectural components.



Figure 2-1 Result of shaking table test on room contents (from 01, 2008 test)

Click on the link below and select one of the following video clips:

–Shaking table tests on room safety issue of a high-rise building (01, 2008)

–Shaking table tests on non-structure furniture in a high-rise building (03, 2007)

<http://www.bosai.go.jp/hyogo/ehyogo/movie.html>

2.1 DEFINITIONS

Buildings consist of both “structural” and “nonstructural” components. The distinction between the two types of building components is described below.

2.1.1 STRUCTURAL COMPONENTS

The structural components of a building resist gravity, earthquake, wind, and other types of loads and typically include the following elements:

- vertical supports such as columns, posts, pillars, and pilasters
- horizontal supports such as trusses, girders, beams, joists, and purlins
- load-bearing walls that provide vertical support or lateral resistance
- diagonal elements such as braces
- floor and roof slabs, sheathing or decking
- foundation systems such as slabs on grade, mats, spread footings, or piles

The structural system of buildings is typically analyzed and designed by a civil or structural engineer and is presented on construction drawings or plans, except in the case of houses. The structural components of a typical building can be seen on Figure 2.1.2–1 by clicking on the “structural components only” button.

2.1.2 NONSTRUCTURAL COMPONENTS

The nonstructural components of a building include all building parts and contents except for those previously described as structural. These components are generally specified by architects, mechanical engineers, electrical engineers, and interior designers. However, they may also be purchased and installed directly by owners or tenants after construction of a building has been completed. In commercial real estate, the architectural and mechanical, electrical, and plumbing systems may be considered a permanent part of the building and belong to the building owner; the furniture, fixtures, equipment and contents, by contrast, typically belong to the building occupants.

In this guide, nonstructural components are divided into three broad categories:

ARCHITECTURAL COMPONENTS such as partitions, ceilings, storefronts, glazing, cladding, veneers, chimney, fences, and architectural ornamentation.

MECHANICAL, ELECTRICAL, AND PLUMBING (MEP) COMPONENTS such as pumps, chillers, fans, air handling units, motor control centers, distribution panels, transformers, and distribution systems including piping, ductwork and conduit.

FURNITURE, FIXTURES & EQUIPMENT (FF&E), AND CONTENTS such as shelving and book cases, industrial storage racks, retail merchandise, books, medical records, computers and desktop equipment, wall and ceiling mounted TVs and monitors, file cabinets, kitchen, machine shop or other specialty equipment, industrial chemicals or hazardous materials, museum artifacts, and collectibles.

The list of nonstructural components is nearly endless and constantly evolving, as new technologies alter our built environment. Figure 2.1.2–1 displays a typical building with nonstructural components discussed in this document, along with typical structural components. Clicking the “structural components only” button strips away the layer of nonstructural components to emphasize the ubiquity of architectural, MEP, and FF&E components in the built environment.

Note that most structural components are typically concealed from view by nonstructural materials, such as architectural finishes. For example, in steel construction, fireproofing is typically applied directly to steel members and then covered with finish materials such as gypsum board. In wood construction, there is usually no way to visually distinguish between a non-load-bearing partition and a structural or shear wall. Steel diagonal braces are often hidden inside walls. Similarly, mechanical, electrical, and plumbing components are also typically concealed by architectural components.

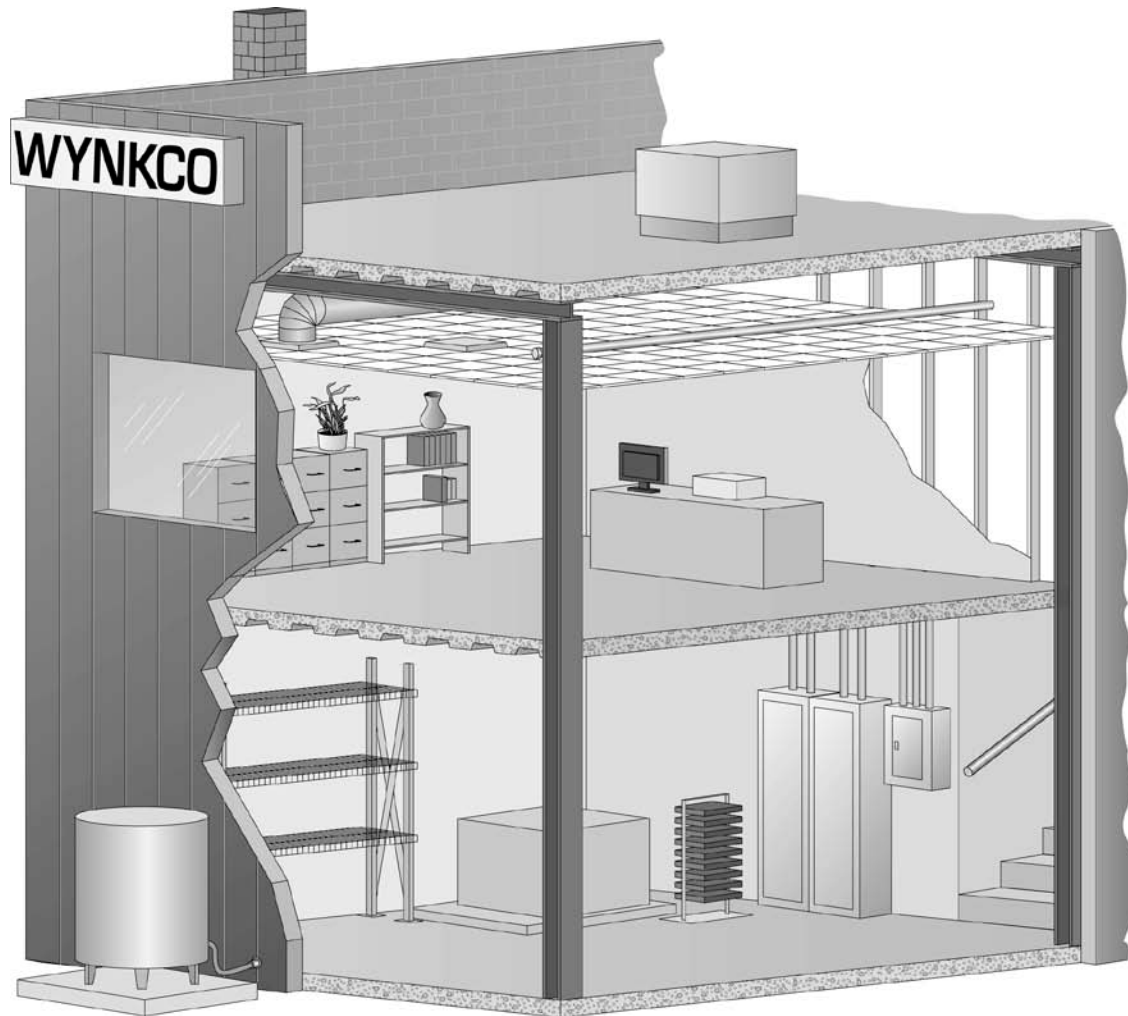


Figure 2.1.2-1 A three-dimensional view of a portion of a building. This figure shows both structural and nonstructural components.

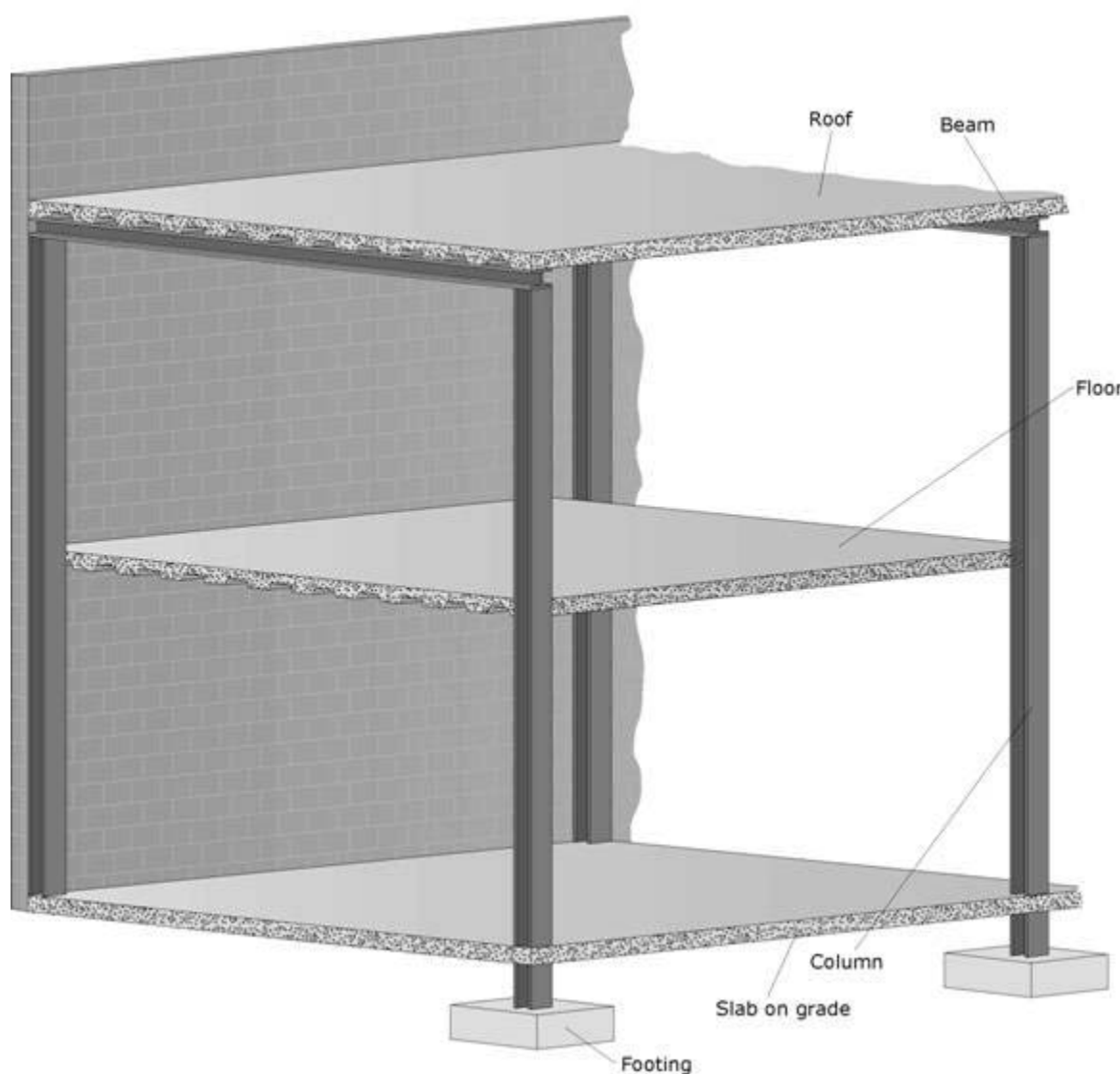


Figure 2.1.2-2 A three-dimensional view of a portion of a building showing structural components only.

2.1.3 RELATIVE COSTS

In general, the structural components of a commercial building account for approximately 15–25% of the original construction cost, while the nonstructural (mechanical, electrical, plumbing, and architectural) components account for the remaining 75–85% of the cost. Contents belonging to the building occupants, such as movable partitions, furniture, and office or medical equipment, represent a significant additional value at risk. When these costs are compared, it becomes clear that the largest capital investment in most commercial buildings is

in the nonstructural systems and contents. This is illustrated in Figure 2.1.3-1 below for three common types of commercial construction (Whittaker and Soong, 2003).

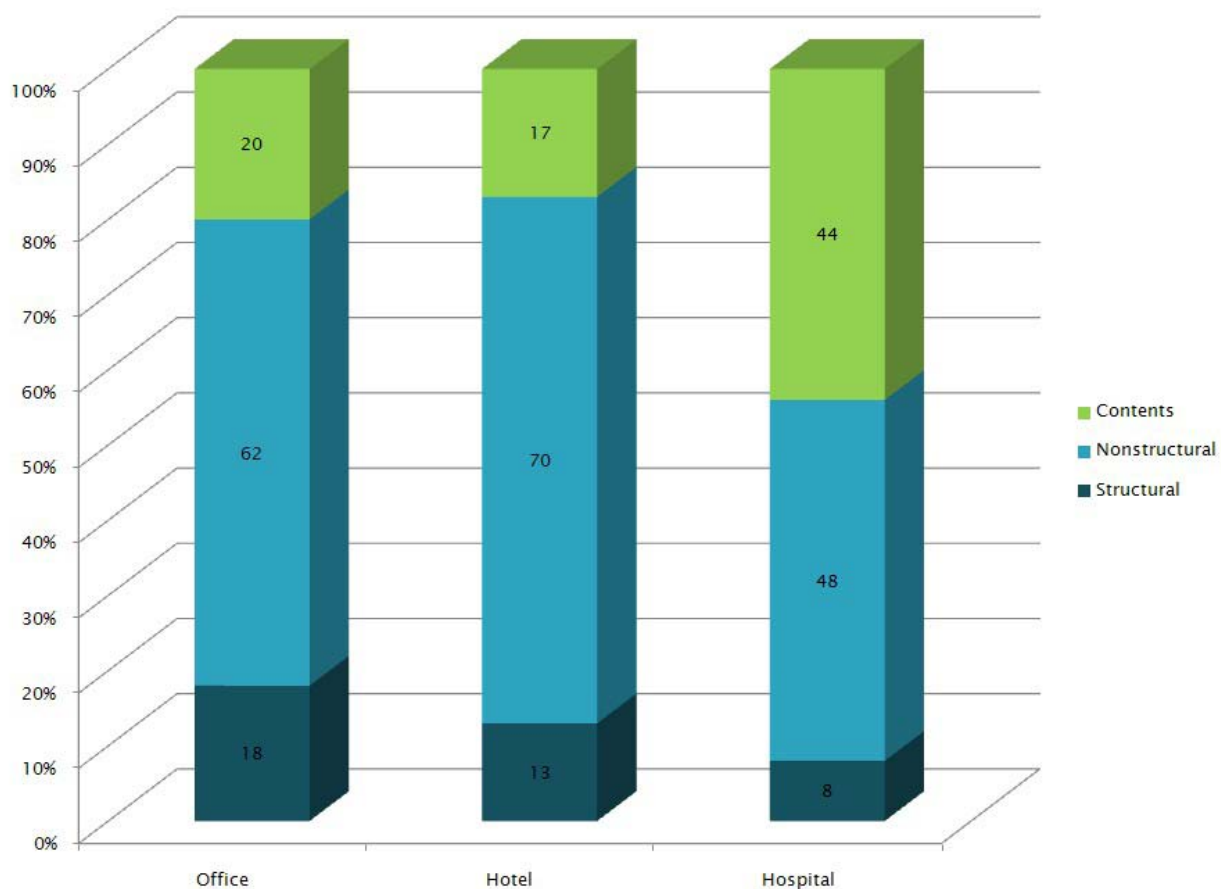


Figure 2.1.3-1 Typical investments in building construction.

2.2 CAUSES OF STRUCTURAL DAMAGE

Earthquake ground shaking causes damage to nonstructural components in four principal ways:

- Inertial or shaking effects cause sliding, rocking or overturning (Section 2.2.1).
- Building deformations damage interconnected nonstructural components (Section 2.2.2).
- Separation or pounding between separate structures damage nonstructural components crossing between them (Section 2.2.3).
- Interaction between adjacent nonstructural components (Section 2.2.4) cause damage.

2.2.1 INERTIAL FORCES

When a building shakes during an earthquake, the base of the building typically moves in unison with the ground. The entire building and its contents above the base experience inertial forces that push them back and forth in a direction opposite to the base excitation. In general, the earthquake inertial forces are greater if the mass of the building is greater, if the acceleration or severity of the shaking is greater, or if the location is higher than the base, where excitations are amplified. Thus, the earthquake forces experienced above the base of a building can be many times larger than those experienced at the base.

When unrestrained or marginally restrained items are shaken during an earthquake, inertial forces may cause them to slide, swing, rock, strike other objects, or overturn (see Figure 2.2.1–1). File cabinets, emergency generators, suspended items, free-standing bookshelves, office equipment, and items stored on shelves or racks can all be damaged as they move and contact other items, fall, overturn or become disconnected from attached components. The shaking can also cause damage to internal components of equipment without any visible damage or movement from its original location.

Analogy: Passenger in a Moving Vehicle

As a passenger in a moving vehicle, you experience inertial forces whenever the vehicle is rapidly accelerating or decelerating. If the vehicle is accelerating, you may feel yourself pushed backward against the seat, since the inertial force on your body acts in the direction opposite to that of the acceleration. If the vehicle is decelerating or braking, the inertia forces may cause you to be thrown forward in your seat.

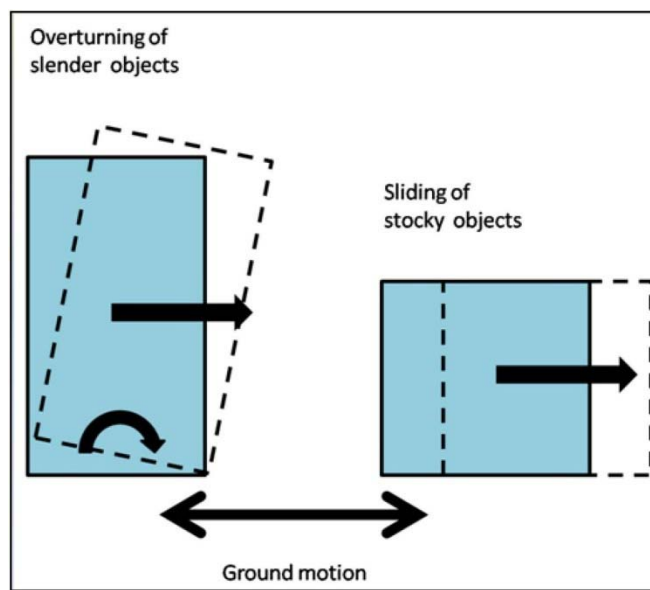


Figure 2.2.1-1 Sliding and overturning due to inertial forces.

2.2.2 BUILDING DEFORMATIONS

During an earthquake, structural members of buildings can deform, bend or stretch and compress in response to earthquake forces. For example, the top of a tall office tower may lean over a few feet in each direction during an earthquake. The horizontal deformation over the height of each story, known as the story drift, might range from a quarter of an inch to several inches between adjacent floors, depending on the size of the earthquake and the characteristics of the particular building structure and type of structural system. The concept of story drift is shown in Figure 2.2.2-1.

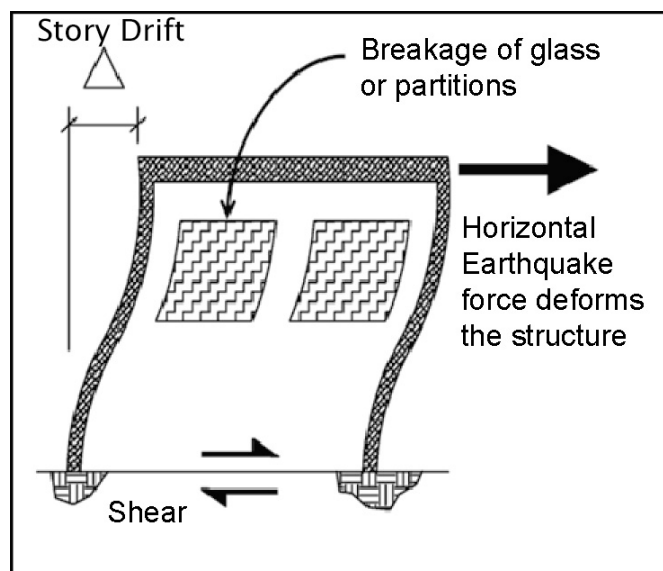


Figure 2.2.2-1 Nonstructural damage due to building deformation.

When the building deforms, the columns or walls deform and become slightly out of square and thus, any windows or partitions rigidly attached to the structure must also deform or displace the same amount. Brittle materials like glass, plaster partitions, and masonry infill or veneer cannot tolerate any significant deformation and will crack when the space between stops or molding closes and the building structure pushes directly on the brittle elements. Once cracked, the inertial forces in the out-of-plane direction can cause portions of these architectural components to become dislodged and to fall far from their original location, possibly injuring passers-by underneath them.

Structural – Nonstructural Interaction: Problem with Short Columns

There have been many notable examples in past earthquakes where rigid nonstructural components have been the cause of structural damage or collapse. These cases have generally involved rigid, strong architectural components, such as masonry infill or concrete spandrels that inhibit the movement or deformation of the structural framing and cause premature failure of column or beam elements. When a structural column is restrained by nonstructural components, it is often referred to as a “short column” or “captive column.” This is a serious concern for the design of structural systems. Designers of nonstructural components must be mindful to isolate their systems from the deformations of the adjacent structural components or to make sure that the structural components have been designed to accommodate the interaction.

2.2.3 BUILDING SEPARATIONS

Another source of nonstructural damage involves pounding or movement across separation or expansion joints between adjacent structures or structurally independent portions of a building. A seismic joint is the separation or gap between two different building structures, often two wings of the same facility, which allows the structures to move independently of one another as shown in Figure 2.2.3-1.

In order to provide functional continuity between adjacent structures or between structurally independent portions of a building, utilities must often extend across these building joints, and architectural finishes must be detailed to terminate on either side. The separation joint may be only an inch or two wide in older construction or a foot or more in some newer buildings, depending on the expected horizontal movement, or seismic drift between buildings. Flashing, piping, conduit, fire sprinkler lines, heating, ventilation, and air-conditioning (HVAC) ducts, partitions, and flooring all have to be detailed to accommodate the seismic movement expected at these locations when the two structures move closer together or further apart. Damage to items crossing seismic separation or expansion joints is a common type of earthquake damage. If the size of the gap is insufficient, pounding between adjacent structures may result, which can damage structural components but more often causes damage to nonstructural components, such as parapets, veneer, or cornices on the façades of older buildings.

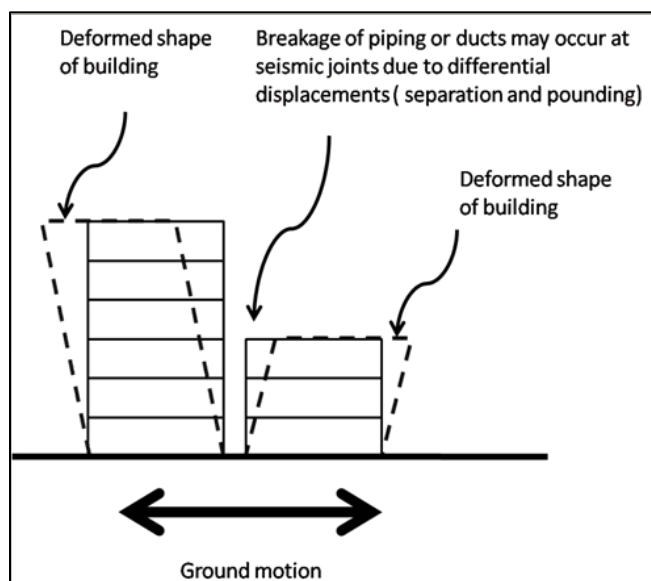


Figure 2.2.3-1 Nonstructural damage due to separation and pounding.

Base-Isolated Buildings

A special type of seismic joint occurs at the ground level of base-isolated buildings, which are separated from the ground by seismic shock absorbers or isolators, in order to reduce the transfer of earthquake accelerations to the building. The seismic joint typically occurs between the foundation below the isolator and the building above. These joints may be as much as several feet wide; special detailing is required for all the architectural finishes and building utilities that cross the joint.

2.2.4 NONSTRUCTURAL INTERACTION

An additional source of nonstructural damage is the interaction between adjacent nonstructural systems which move differently from one another. Many nonstructural components may share the same space in a ceiling plenum or pipe chase; these items may have different shapes, sizes, and dynamic characteristics, as well as different bracing requirements.

Some examples of damaging nonstructural interactions include:

- Sprinkler distribution lines interact with the ceiling causing the sprinkler heads to break and leak water into the room below.
- Adjacent pipes of differing shapes or sizes are unbraced and collide with one another or adjacent objects..
- Suspended mechanical equipment swings and impacts a window, louver, or partition.
- Ceiling components or equipment can fall, slide, or overturn blocking emergency exits.

2.3 EXTENT OF NONSTRUCTURAL DAMAGE

There are many factors affecting the performance of nonstructural components during an earthquake and the extent to which they will sustain damage. The degree of damage caused by the four principal effects previously described depends upon considerations such as the components' dynamic characteristics, their location in the building, and their proximity to other structural or nonstructural components. Other factors include the type of ground motion, the structural system of the building, the location and placement of the loads, the type of anchorage or bracing, if any, the strength of the structural supports used for anchorage, potential interaction with other nonstructural components, and the potential for secondary damage.

A survey of 25 damaged commercial buildings following the 1971 San Fernando Earthquake revealed the following breakdown of property losses: structural damage, 3%; electrical and mechanical, 7%; exterior finishes, 34%; and interior finishes, 56%. A similar survey of 50 damaged high-rise buildings, which were far enough away from the earthquake fault rupture to experience only mild shaking, showed that whereas none had major structural damage, 43 of the buildings suffered damage to drywall or plaster partitions, 18 suffered damaged elevators, 15 had broken windows, and 8 incurred damage to their air-conditioning systems (Steinbrugge and Schader, 1973).

ATC-69 *Reducing the Risks of Nonstructural Earthquake Damage, State-of-the-Art and Practice Report* (ATC, 2008) summarizes the current state of knowledge and practice regarding the seismic performance of nonstructural components of buildings. This study confirmed the lack of systematic and comprehensive post-earthquake documentation of nonstructural performance and recommended development of a standardized framework for the collection of future nonstructural earthquake damage data.

Engineering Considerations: Extent of Damage

- Unique characteristics of the ground shaking at the site (e.g., high or low frequency motion, proximity to fault)
- Characteristics of the structural system supporting the nonstructural elements (e.g., the structure may be tall and flexible, short and stiff, or short and flexible)
- Location of the nonstructural item within the building (e.g., items may be at the basement, at mid-height or roof level; items may cross seismic joints or may be located in close proximity to deforming structural elements)
- Distribution and placement of loads (e.g., heavy loads situated near the bottom of shelving units and lighter items above, or the reverse; countertop lab equipment close or far from the edges of counters)
- Anchorage or restraint conditions (e.g., items may be unanchored, marginally anchored, or well anchored)
- Condition of structural elements used for anchorage (e.g., location and strength of studs in a wall used to anchor tall cabinets or shelving, location of reinforcing bars in concrete used to anchor heavy items, condition of mortar in old masonry walls)
- Potential interaction with structural elements or other nonstructural elements (e.g., rigid granite veneer covering a flexible steel column or a well-anchored ceiling grid with unbraced sprinkler lines).
- Potential for secondary damage caused by release of fluids, gases, toxins, asbestos, and other hazardous substances (e.g., damage to asbestos insulation requires evacuation, a gas leak results in a fire)

2.4 IMPORTANCE OF NONSTRUCTURAL DAMAGE

Historically, earthquake engineers have focused on the performance of structural systems and ways to mitigate structural damage. As the earthquake engineering community moves toward more comprehensive earthquake standards and expectations of improved seismic performance, and as the public demands a higher level of earthquake protection, it is important to understand the significance of nonstructural damage.

The failures of nonstructural components during an earthquake may result in injuries or fatalities, cause costly property damage to buildings and their contents; and force the closure of residential, medical and manufacturing facilities, businesses, and government offices until appropriate repairs are completed. As stated previously, the largest investment in most buildings is in the nonstructural components and contents; the failures of these elements may be both dangerous and costly. The potential consequences of earthquake damage to nonstructural components are typically divided into three types of risk:

- **Life Safety (LS)** *Could anyone be hurt by this component in an earthquake?*
- **Property Loss (PL)** *Could a large property loss result?*
- **Functional Loss (FL)** *Could the loss of this component cause an outage or interruption?*

Damage to a particular nonstructural item may present differing degrees of risk in each of these three categories. In addition, damage to the item may result in direct injury or loss, or the injury or loss may be a secondary effect or a consequence of the failure of the item.

The focus of this guide is on nonstructural hazards; nevertheless, existing structures may also have structural hazards that pose risks to life safety, property, and functionality. While it may make sense to implement simple and inexpensive nonstructural protection measures even in a building with structural hazards, the relative structural and nonstructural risks should be considered, so that limited resources can be used in the most effective manner. It would give little comfort to know that the pipes and ceilings were all well anchored in an unreinforced masonry structure that could collapse during an earthquake.

The three risk categories are also sometimes referred to as:
the **3Ds**: Deaths, Dollars, and Downtime;
the **3Cs**: Casualties, Cost, and Continuity;
or merely Safety, Property, and Function.

2.4.1 LIFE SAFETY (LS)

The first type of risk is that people could be injured or killed by damaged or falling nonstructural components. Heavy exterior cladding dislodged during earthquakes has killed passersby (Tally, 1988; Adham and Brent, 1985). Even seemingly harmless items can cause death if they fall on a victim. If a 25-pound light fixture not properly fastened to the ceiling breaks loose during an earthquake and falls on someone's head, the potential for injury is great. Life safety can also be compromised if the damaged nonstructural components block safe exits in a building. Damage to life safety systems such as fire protection piping can also pose a safety concern should a fire start following an earthquake. Examples of potentially hazardous nonstructural damage that have occurred during past earthquakes include broken glass, overturned tall, heavy cabinets and shelves, falling ceilings and overhead light fixtures, ruptured gas lines and other piping containing hazardous materials, damaged friable asbestos materials, falling pieces of decorative brickwork and precast concrete panels, dislodged contents stored overhead, and collapsed masonry parapets, infill walls, chimneys, and fences.

The following anecdotes from past earthquakes will help to illustrate the point. Damage photos are shown in Figures 2.4.1–1 thru 2.4.1–5. Additional damage photos are provided in Chapter 6.

- More than 170 campuses in the Los Angeles Unified School District suffered nonstructural damage during the 1994 Northridge, California earthquake. At Reseda High School, the ceiling in a classroom collapsed and covered the desks with debris. The acoustic ceiling panels fell in relatively large pieces, 3 feet or 4 feet square, accompanied by pieces of the metal ceiling runners and full-length sections of fluorescent light fixtures. Because the earthquake occurred during hours when the building was unoccupied, none of the students were injured (Los Angeles Times, 1994).
- A survey of elevator damage following the 1989 Loma Prieta Earthquake revealed 98 instances in which counterweights came out of the guide rails and six instances where the counterweight impacted the elevator cab, including one case in which the counterweight came through the roof of the cab. No injuries were reported (Ding, 1990). An elevator survey following the Northridge Earthquake indicated 688 instances in which counterweights came out of the guide rails, in addition to reports of other types of elevator damage. An occurrence of a counterweight becoming dislodged and impacting the elevator cab was captured on film during the 2010 Chile Earthquake.

- One hospital patient on a life-support system died during the 1994 Northridge Earthquake because of failure of the hospital's electrical supply (Reitherman, 1994).
- During the 1993 Guam Earthquake, the fire-rated nonstructural masonry partitions in the exit corridors of one resort hotel were extensively cracked, causing many of the metal fire doors in the corridors to jam. Hotel guests had to break through the gypsum wallboard partitions between rooms in order to get out of the building, a process that took as long as several hours. It was fortunate that the earthquake did not cause a fire in the building and no serious injuries were reported.
- Damage to industrial storage racks commonly used in “big box” stores has been reported in most recent earthquakes. Damage has ranged from dislodged contents to partial collapse of racking systems. Collapsed racking systems have been documented in both the 1994 Northridge Earthquake and the 2010 Christchurch New Zealand Earthquake. To date, related deaths and casualties have been avoided due to limited occupancy at the time of earthquake shaking.



Figure 2.4.1-1 Failure of office partitions, ceilings, and light fixtures in the 1994 Northridge Earthquake (FEMA 74, 1994).



Figure 2.4.1-2 Shards of broken untempered glass that fell several stories from a multistory building in the 1994 Northridge Earthquake. Failures of this type can be very hazardous, especially if glazing is located above exit ways (FEMA 74, 1994).



Figure 2.4.1-3 Failure of suspended ceilings and light fixtures in a furniture store (FEMA 74, 1994).



Figure 2.4.1-4 Failure of heavy stucco soffit at building entrance in the 1994 Northridge Earthquake (FEMA 74, 1994).



Figure 2.4.1-5 Damage to overloaded racks during the 1994 magnitude-6.7 Northridge Earthquake (FEMA 460, 2005).

2.4.2 PROPERTY LOSS (PL)

As discussed previously, nonstructural components, such as mechanical and electrical equipment and distribution systems and architectural components, account for 75–85% of the original construction costs of a typical commercial building. Contents belonging to the building occupants, such as movable partitions, furniture, and office or medical equipment, represent a significant additional value at risk. For example, a high tech fabricating facility may have contents that are worth many times the value of the building and built-in components of the building. Immediate property losses attributable to contents alone are often estimated to be one third of the total earthquake losses (FEMA, 1981).

Property losses may be the result of direct damage to a nonstructural item or of the consequences produced by its damage. If water pipes or fire sprinkler lines break, then the overall property losses will include the cost to repair the piping (a primary or direct loss), plus the cost to repair water damage to the facility (a secondary or indirect loss). If the gas supply line for a water heater ruptures and causes a fire, then clearly the property loss will be much greater than the cost of a new pipe fitting. Many offices and small businesses suffer losses as a result of nonstructural earthquake damage but may not keep track of these losses unless they have earthquake insurance that will help to cover the cleanup and repair costs.



Figure 2.4.2-1 Complete loss of suspended ceilings and light fixtures in the 1994 Northridge Earthquake (FEMA 74, 1994).



Figure 2.4.2-2 Damage to inventory on industrial storage racks in the 1994 Northridge Earthquake (FEMA 74, 1994).

The nonstructural property losses can be much larger if they occur at library and museum facilities whose function is to store and maintain valuable contents. For example, as a result of the 1989 Loma Prieta Earthquake, two libraries in San Francisco each suffered over a million dollars in damage to building contents; the money was spent primarily on reconstructing the library stacks, rebinding damaged books, and sorting and reshelving books. At one of these facilities, \$100,000 was spent rebinding a relatively small number of rare books alone (Wong, 1993; Dobb, 1993).

2.4.3 FUNCTIONAL LOSS (FL)

In addition to life safety and property loss considerations, there is the additional possibility that nonstructural damage will make it difficult or impossible to carry out the functions that were normally accomplished in a facility. After life safety threats have been addressed, the potential for postearthquake downtime or reduced productivity is often the most important risk. For example, if a business loses the use of its computers, filing system, or other instruments of service as a result of earthquake damage, then the dollar loss of replacing the damaged items may be relatively small, but the loss in revenue associated with downtime during recovery can be tremendous. In light of the global economy, loss of function can also translate to longer term loss of market share for some businesses as consumers find alternate suppliers for needed goods or services.

Many external factors may affect postearthquake operations, including power and water outages, damage to transportation systems, availability of materials and contractors to repair damage, civil disorder, police lines, and curfews. These effects are generally outside the control of building owners and tenants and beyond the scope of this discussion.

The following are examples of nonstructural damage that resulted in interruptions to postearthquake emergency operations or to businesses:

- During the 1994 Northridge Earthquake, nonstructural damage caused temporary closure, evacuation, or patient transfer at ten essential hospital facilities. These hospitals generally had little or no structural damage but were rendered temporarily inoperable, primarily because of water damage. At the majority of these facilities, water leaks occurred when fire sprinkler, chilled-water, or other pipelines broke. In some cases, personnel were unavailable or unable to shut off the water, and water was flowing for many hours. At one facility, water up to 2 feet deep was reported at some locations in the building as a result of damage to the domestic water supply tank on the roof. At another facility, the emergency generator was disabled when its cooling water line broke where it crossed a separation joint. Other damage at these facilities included broken glass, dangling light fixtures, elevator counterweight damage, and lack of emergency power due to failures in the distribution or control systems. Two of these facilities, shown in the following figures, Los Angeles County Olive View Medical Center and Holy Cross Medical Center, both in Sylmar, California, that had suffered severe structural damage or collapse during the 1971 San Fernando Earthquake had been demolished and entirely rebuilt by the time of the 1994 Northridge Earthquake (Reitherman, 1994).

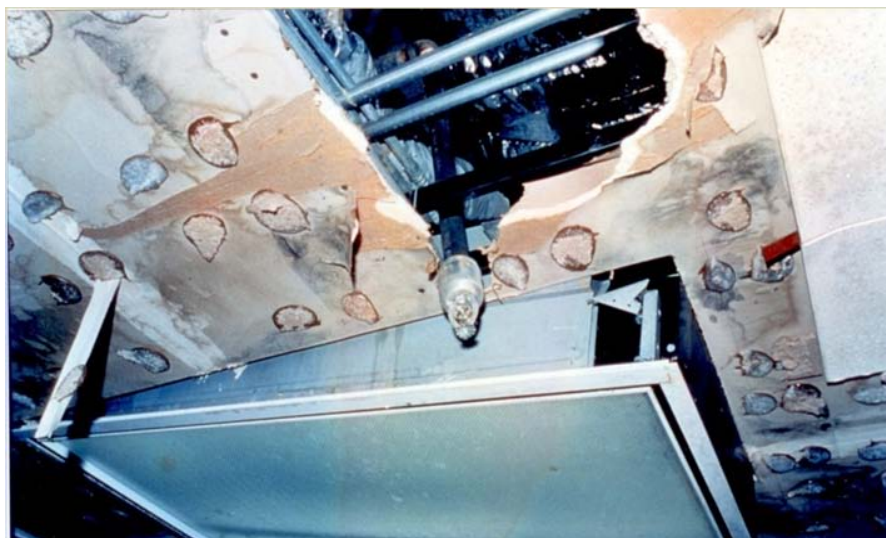


Figure 2.4.3-1 Broken sprinkler pipe at Olive View Hospital in Sylmar, California as a result of the 1994 Northridge, Earthquake. Pipe ruptured at the elbow joint due to differential motion of the pipe and ceiling (FEMA 74, 1994).

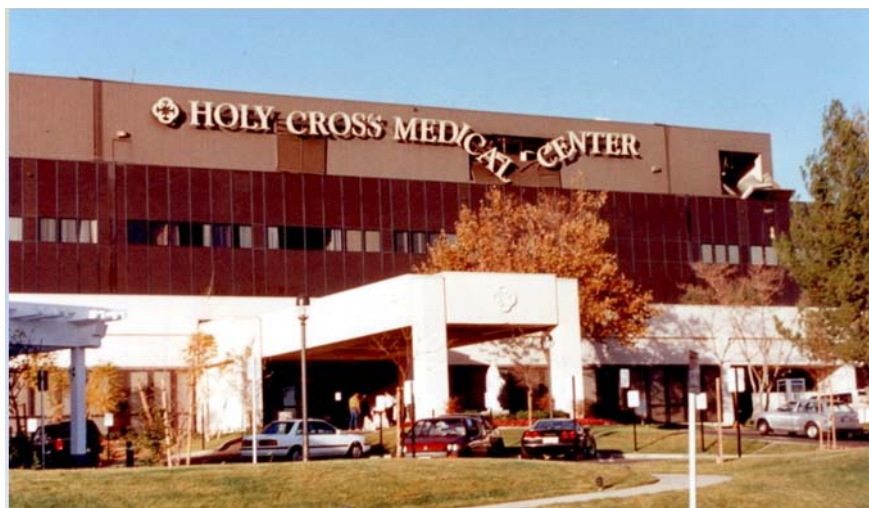


Figure 2.4.3-2 HVAC damage at Holy Cross Medical Center in Sylmar in the 1994 Northridge Earthquake. Damage to signage and louvers was caused when suspended fans in the mechanical penthouse swung and impacted the louver panels. HVAC service outage caused the temporary evacuation of patients (FEMA 74, 1994).

- Of 32 commercial data processing facilities surveyed following the 1989 Loma Prieta Earthquake, at least 13 were temporarily out of operation for periods ranging from 4 to 56 hours. The primary cause of outage was loss of outside power. Reported damage included overturning of equipment at two facilities, damage to access floors at four facilities, movement of large pieces of computer equipment over distances ranging from

a few inches to 4 feet at 26 facilities, and dislodged ceiling panels at 13 facilities.

Twenty of these facilities reported having an earthquake preparedness program in place at the time of the earthquake, three reported having no program, and information was unavailable for nine facilities (Ding, 1990).

- The 1971 San Fernando Earthquake caused extensive damage to elevators in the Los Angeles area, even in some structures where no other damage was reported. An elevator survey indicated 674 instances in which counterweights came out of the guide rails, in addition to reports of other types of elevator damage. These elevators were inoperable until they could be inspected and repaired. Many thousands of businesses were temporarily affected by these elevator outages. The State of California instituted seismic elevator code provisions in 1975 with the intent of allowing for safe elevator shutdown during and after an earthquake (not to make the elevators so earthquake-resistant that they can be relied upon for exiting buildings immediately after an earthquake). While these provisions appear to have helped reduce elevator damage, there were still many instances of counterweight damage in the San Francisco area following the 1989 Loma Prieta Earthquake, and 688 cases in the Northridge Earthquake in 1994 (Ding, 1990; Reitherman, 1994). . Since the State of California seismic elevator code provisions have not been adopted nationally, elevator damage – including the potential for life-threatening conditions – remains a concern.

In some cases, cleanup costs or the value of lost employee labor are not the key measures of the postearthquake impact of an earthquake. For example, data processing facilities or financial institutions must remain operational on a minute-by-minute basis in order to maintain essential services and to monitor transactions at distant locations. In such cases, spilled files or damage to communications and computer equipment may represent less tangible but more significant outage costs. Hospitals and fire and police stations are facilities with essential functions that must remain operational after an earthquake.

2.5 COMMON TYPES OF NONSTRUCTURAL EARTHQUAKE DAMAGE

Many types of nonstructural components can be damaged in earthquakes, but the items that are most vulnerable and most likely to result in injuries, significant property losses, and interruption will be described here in terms of the risk posed to life safety, property, and functionality.

2.5.1 LIFE SAFETY

Heavy exterior cladding

Cladding is an architectural element used to provide the exterior skin for buildings. Often constructed of heavy precast concrete panels, these panels typically have four support points, two at the top of the panel connecting it to the beam above, and two at its base connected to the level below. Unless specifically designed to accommodate the anticipated inter-story drift and out-of-plane seismic forces, these supports can fail. A female student was killed in the 1987 Whittier Narrows Earthquake when a 5,000-pound precast panel fell 25 feet off of the exterior of a parking garage at California State University, Los Angeles. The student was attempting to exit from the ground floor parking level when she was struck by the falling panel (Taly, 1988).

Heavy interior walls

Nonstructural walls in older buildings are often built of heavy, unreinforced masonry materials such as brick, concrete block, or hollow clay tile. These materials are advantageous for fire and sound proofing and thermal insulation, but are brittle since they do not have a grid of horizontal and vertical steel reinforcing bars embedded in them. Falling masonry in hallways and stairwells is a particular hazard for occupants attempting to exit buildings during an earthquake.

Threshold for Damage to Unreinforced Masonry:

Masonry damage has long been used to estimate earthquake ground motion intensity in the absence of instrumental recordings. The Modified Mercalli Intensity (MMI) scale identifies levels I to XII to characterize the seismic intensity. MMI Intensity VI and VII both include descriptions of cracked masonry that can be used to estimate the level of ground shaking (Richter, 1957).

Recent efforts to correlate the MMI scale with recorded peak ground accelerations (PGAs) suggest that the threshold for masonry damage, MMI Intensity VI, is associated with low levels of seismic excitation with PGAs in the range 0.10g to 0.15g (CISN, 2009).

Unbraced masonry parapets or other heavy building appendages

Unreinforced masonry parapets are a common feature of vintage commercial construction in many parts of the country. Parapets are the short walls around the perimeter of a roof, constructed to help prevent fire from jumping from one roof to the next, to provide guardrail protection for people on the roof, to hide roof-mounted equipment, or to provide an architectural effect of greater height. While some communities have enforced ordinances that require unreinforced masonry parapets to be braced or anchored, many jurisdictions have no such mandatory provisions. As these parapets often fail at the roofline and fall outwards onto the sidewalk, they represent a particular hazard for pedestrians and occupants attempting to exit damaged buildings. Two children were killed on their way to school due to falling unreinforced stone masonry in Challis, Idaho during the 1983 Borah Peak, Idaho earthquake (Adham and Brent, 1985). Unreinforced masonry parapets have also fallen inward and penetrated through the roof of buildings.

Unreinforced masonry chimneys

Residential chimneys are typically built of brittle unreinforced brick masonry that may be damaged even in relatively small earthquakes. This is also true of many commercial chimneys. Broken chimneys can fall through the roof and pose a safety risk to building occupants. The 1992 Landers Earthquake caused one related fatality where a child was sleeping next to a fireplace. A similar fatality occurred in the 2000 Napa earthquake where a child sleeping next to a fireplace was killed during a slumber party. Chimneys can also fall against the side of the building, onto an adjacent building or onto a public sidewalk, posing a hazard to neighbors or passersby. Use of a cracked flue chimney can cause an indirect hazard when carbon monoxide enters a home or leads to ignition of a fire.

Suspended lighting

Suspended overhead lighting is prone to damage in earthquakes, especially if the lights are supported solely by unbraced suspended ceilings, or if they interact with unbraced piping or other suspended components. There were several instances where suspended lighting fixtures in Los Angeles school district classrooms fell during the 1994 Northridge Earthquake. No casualties occurred since school was not in session at the time of the earthquake.

Large, heavy ceilings

Heavy suspended ceilings and soffits can be damaged during earthquakes, sometimes causing heavy and dangerous material to fall and injure people below. Figure 2.4.1–2 shows a failed

stucco soffit above a building entrance damaged in the 1994 Northridge Earthquake. During the 1989 Loma Prieta Earthquake, the proscenium arch ceiling at the Geary Theatre in San Francisco fell and covered the first six rows of seats in the auditorium; the theater was not in use at the time and no one was injured (Ding, 1990).

Tall, slender, and heavy furniture such as bookcases and file cabinets

Tall slender shelving, bookcases, or file cabinets frequently overturn during earthquakes if they are unanchored or poorly anchored. These items are particularly hazardous if they are located adjacent to a desk or bed or located where they can jam doors or block corridors and exits. Recent shaking table tests conducted in Japan predict injuries to occupants represented by mannequins crushed by tall unanchored pieces of furniture.

Heavy unanchored or poorly anchored contents, such as televisions, computer monitors, countertop laboratory equipment, and microwaves

Heavy contents situated above the floor level include a wide range of items that could become falling hazards in an earthquake. Many rooms have overhead wall- or ceiling-mounted televisions and monitors, offices have desktop computer monitors, or microwaves may be perched high on counters or shelves. Any of these items could cause injury if they fell and hit someone; damage to fallen items can add to property loss and downtime. During the 1989 Loma Prieta Earthquake, an overhead monitor fell at the San Francisco International Airport, hitting a passenger on the shoulder.

Glazing

Damage to storefront windows in older commercial buildings is common during earthquakes, often causing hazardous conditions on sidewalks in commercial areas. Glazing failures were relatively common in high-rise buildings in Mexico City in the 1985 Earthquake. U.S. earthquakes have not yet caused numerous high-rise glazing failures, though it remains a possibility.

Fire protection piping

Damage to suspended fire protection piping and other system components can render the system inoperable following an earthquake. The resultant loss of fire life safety protection can pose a serious risk to the life safety of building occupants.

Hazardous materials release

There have been a number of examples of hazardous materials release resulting from earthquake damage to piping, stored chemicals, commercial, medical, or educational laboratory facilities. Breakage of containers of chemicals can cause them to mix and lead to hazardous reactions. Exposure of asbestos materials due to earthquake activity has also resulted in the postearthquake evacuation of facilities that otherwise had little structural damage.

Gas water heaters

Residential and small commercial water heaters have ignited fires following earthquakes, in instances where the gas supply line was damaged. As water heaters are typically tall and slender, the gas supply line can break if the water heater tips over.

2.5.2 PROPERTY LOSS

Suspended piping for water or waste

Failures of suspended piping have lead to costly property loss in past earthquakes. While such failures are not often associated with life threatening injuries, they often result in costly property loss: both the cost to replace the damaged system and the cost to repair damage caused by the release of both clean and contaminated or hazardous fluids. Secondary damage due to fluid release is often a large component of nonstructural property losses.

Suspended fire protection piping

Failures of suspended fire protection piping have resulted in both direct and indirect property loss following earthquakes. Some of these systems have failed or fallen and had to be replaced. More costly are the failures of sprinkler piping, connections, or sprinkler heads. These have resulted in the release of great volumes of water in plenum or occupied spaces. Flooded plenums have resulted in collapsed ceilings which cause the consequent loss of property and disruption of operations. In extreme cases, entire floors or buildings were abandoned as a result of the water damage. Flooding in occupied spaces has resulted in water damage to furniture, files, computer equipment, and interior finishes. As fire sprinkler lines are widespread in occupied spaces, this type of failure has been one of the most costly types of nonstructural damage.

Unanchored and poorly anchored equipment, particularly roof-mounted equipment and unrestrained vibration-isolated equipment

Roof-mounted HVAC equipment is often vulnerable to earthquake damage, in part because the seismic accelerations are typically larger at the roof level than they are at the lower levels of the building. Such equipment is often mounted on vibration-isolation springs to prevent the transmission of the equipment vibrations to the building and building occupants. While these springs allow the equipment to move vertically a small amount in order to isolate its rapid vibratory motion from the building, this equipment is especially vulnerable to the much larger motions caused by an earthquake, unless it is also designed with seismic restraints. Damage to roof-mounted equipment, as well as other suspended or floor-mounted equipment, can disable the infrastructure of a building.

Partitions

Non-load-bearing gypsum board partitions can be detailed to reduce the impact of seismic distortions of structural systems, with a connection detail at the top of the partition that allows the interface with the floor or roof above to accommodate sliding. However, this often is not detailed properly, resulting in extensive cracking and tearing at joints and points of attachment. Heavy partitions constructed of concrete masonry units, brick, or hollow clay tile are also often damaged in earthquakes and are costly to repair. Even when partition damage is minor to moderate, it may still necessitate complete interior patching and painting and may cause business interruptions in the affected interior spaces. Pacific Gas & Electric Company, which operates throughout much of Northern California, reported close to \$50 million in area-wide property damage following the 1989 Loma Prieta Earthquake, much of which was from damage to gypsum board partitions, glazing, and air conditioning units. While this nonstructural damage represented relatively minor losses for each building, it added up to large aggregate losses for the firm (Ding, 1990).

Ceilings

Suspended ceiling systems have failed in many earthquakes resulting in major repair or replacement costs for the ceilings and interconnected lighting or fire sprinkler lines as well as interruption in the use of the occupied spaces.

Hazardous Materials Release

Release of some hazardous materials can create a point of ignition for a fire. An entire three story university chemistry building burned down to the steel frame as a result of a hazardous materials release in the 2010 Chile Earthquake (see Section 6.5.4.1).

2.5.3 FUNCTIONAL LOSS

Emergency generators for critical facilities and related components such as day tanks, batteries, and mufflers

Continued operations of critical facilities following an earthquake depend on the integrity not only of the emergency generator itself but also of many related subcomponents such as batteries, battery racks, day tanks, exhaust and sometimes water-cooling connections, electrical connections to control panels, and mufflers. All of these items must be adequately restrained or anchored in order for the emergency systems to remain operational.

Suspended piping for water or waste

As noted above, damage to these systems results not only in primary damage to the piping and connected systems but also can result in costly outages resulting from the release of fluids into occupied spaces. Also, many facilities cannot operate without water and sanitary sewage service. As an additional concern, process piping may require extensive inspection prior to equipment restart, whether it appears damaged or not, resulting in additional time for functional loss.

Suspended fire protection piping

Failures of suspended fire protection piping have resulted in costly business interruption as well as disabling hospitals in past earthquakes. The small bore lines and sprinkler heads often are built in a grid with ceiling and lighting systems; incompatible motions of these systems have sometimes resulted in damage to the sprinkler heads and subsequent overhead water release.

Hazardous materials release

Breakage of containers of chemicals can cause them to mix and lead to hazardous reactions. Also, due to disruption of building materials, asbestos release has occurred during earthquakes. Any of these types of releases can cause building closures, evacuation, and costly delays until specially trained HAZMAT crews can be brought in to identify and clean the spills.

Failure of equipment needed for functionality, such as computer data centers, controls, servers, hubs, routers, switches, and communication systems

Computer networks form the backbone of many operations. Earthquake damage can result in extended downtime.

Equipment needed for functionality, including HVAC systems

Many facilities cannot maintain operations without HVAC equipment because temperature control and air filtration systems are required in many hospitals, laboratories, and high tech manufacturing facilities.

Equipment needed for functionality, such as elevators and conveyors

Many facilities cannot resume normal operations without the use of passenger and freight elevators or material conveyors. Hospitals need elevators to move gurneys and portable equipment from floor to floor. Occupants of multistory buildings depend upon the use of elevators to move work materials, supplies, and equipment.

3. SURVEY AND ASSESSMENT

PROCEDURES FOR EXISTING BUILDINGS

The first step toward reducing the nonstructural hazards in an existing building is to perform a survey to assess the extent and magnitude of the potential risks. This chapter includes survey guidelines for nonstructural components and describes the inventory form, the checklist, and the risk ratings that are included in the appendices. In order to make informed decisions regarding nonstructural seismic risks, owners and managers will need to address the following questions:

- What types of nonstructural components are present in a particular facility?
- Are these items adequately braced or anchored?
- How will a specific nonstructural item perform in an earthquake, and what are the consequences of failure of that item in terms of life safety, property loss, and functional loss?
- If the decision is made to upgrade a facility, which problems should be addressed first?

The focus of this guide is on reducing nonstructural seismic hazards, particularly in those areas where the seismic shaking intensity is expected to be moderate or high and where significant structural hazards do not exist or will be addressed independently. A simplified map of probable shaking intensities is presented in Figure 3.2.1–1. If the expected shaking for the facility in question is minimal, then the survey procedures and seismic protection measures described in this guide might be undertaken on a voluntary basis but may not be necessary, and in most cases they would not be required for new construction.

3.1 SURVEY OF NONSTRUCTURAL COMPONENTS

The nonstructural components listed in the tables and checklists provided in the appendices are at least initially within the scope of the construction of a building and its building permit. After occupancy of the building, these are items that are most commonly found in commercial,

multiple-unit residential, or public buildings. A complex facility such as a hospital, research laboratory, or industrial plant will contain many additional types of specialized equipment that are not explicitly addressed in this guide.

The goal of a facility survey is to identify nonstructural components that may be vulnerable to earthquake damage. As noted earlier, it may be advisable to seek the help of a professional with expertise in this area. During the survey, the following three basic questions should be kept in mind as each nonstructural item is considered:

- Could anyone get hurt by this item in an earthquake? (Life Safety)
- Could a large property loss result? (Property Loss)
- Would interruptions and outages be a serious problem? (Functional Loss)

For some components, the answers to these three questions may not be immediately obvious, since failure of an item may result in both direct damage and indirect damage. It is important not only to view each item as a discrete object that could tip or fall and hurt someone directly, but also to consider the consequences of failure. Several examples will serve to illustrate the point:

- If a fire sprinkler line breaks, this may cause minor damage to the sprinkler itself but result in major damage to architectural finishes and contents of the building. Even if the building does not sustain any other damage, the occupants may not be able to use the facility until the fire safety system is repaired. The potential for direct and indirect property losses in this case are much greater than the repair cost for the sprinkler system.
- The battery rack used to start an emergency generator is generally located in a locked mechanical room and is unlikely to hurt anyone, even if the rack and batteries fall on the floor. In this case, even though the direct life safety threat is probably low, if the fallen batteries cannot start the emergency generator, building occupants may be injured attempting to evacuate the building in the dark, or the lives of hospital patients on life-support systems may be jeopardized. Thus the indirect losses are larger than the direct losses.
- Gas-fired residential water heaters have rarely injured anyone as they fall, but they have frequently caused postearthquake fires due to ruptured gas lines.

A word of caution is in order regarding the field survey. While it may be relatively straightforward to assess whether or not an item is positively restrained to resist earthquake forces, the effectiveness of the restraint must also be judged. In the case of bookshelves in an

office area, there may be hardware anchoring the shelving to the wall, but unless the hardware is secured to a solid wall or directly to a stud in a partition wall that is also braced, the anchorage may be ineffective in a strong earthquake. The illustrated examples in Chapter 6 show many photos of unanchored, poorly anchored, and well anchored nonstructural components and provide seismic mitigation details for many common situations. As shown in the flowchart in Chapter 1, the reader is advised to complete Chapters 4 and 5 (as applicable) and to review the illustrations and details in Chapter 6 before performing a facility survey and reviewing the questions in the checklist. If the checklist asks whether or not something is securely anchored, then the existing situation should be compared to the seismic mitigation details shown in Chapter 6 for that or a similar item. Also, the installation notes in Section 6.6 provide general guidance on recommended hardware and procedures.

3.1.1 SURVEY FORMS

The field survey may be performed by using the forms and checklists in Appendices C, D, and E.

Appendix C, the Nonstructural Inventory Form, shown in Figure 3.1.1–1 contains a blank nonstructural inventory form that can be used to record field observations. At the start of the survey, this form should be filled in, in order to identify the facility. This inventory form provides a place to record field observations made while walking through the facility and reviewing the questions in the checklist in Appendix D. When an item in the checklist is noncompliant, it should be entered as a line item in the inventory form. The form also contains space to add risk ratings from Appendix E according to the facility's seismic shaking intensity; this could be done during the field survey or could be added to the form later. The space provided for notes may be used to identify the type of problem observed, such as "unanchored" or "bolts undersized."

During the initial survey, it may be helpful to create a list containing a large number of items which may be

Nonstructural Survey Methods for Engineers

The survey method provided here was developed for use by non-engineers. Nonstructural survey methods for use by engineers are available both in ASCE 31/SEI 31–03 Seismic Evaluation of Existing Buildings (ASCE, 2003) and in Chapter 11 of ASCE/SEI 41–06 Seismic Rehabilitation of Existing Buildings (ASCE, 2006).

The evaluation methods described in these ASCE documents are more quantitative than those presented here and often require that engineering calculations be performed to determine the adequacy of the existing conditions.

shortened later, perhaps by dropping low-priority items. At the initial stage, it is better to be conservative and to overestimate vulnerabilities than to be too optimistic. In this version, Appendix C is provided as a sample of the inventory form prepared by the U.S. Bureau of Reclamation. The electronic file containing the sorting algorithm can be downloaded from the Bureau's website at <http://www.usbr.gov/ssle/seismicsafety/onlineorders.html>.

PRIORITIZED INVENTORY										Rank by LS	Rank by Highest Rank
ID	Description	Location	Quantity	Units	LS	PL	LF	Detail Type	Notes	Rank by PL	
					"H", "M", or "L"			NE, PR, ER		Rank by LF	
1	Bookcase in the south east corner	Room 13	2	each	H	M	M	NE	The two wooden bookcases are unanchored and could tip over during an earthquake blocking egress. Relocate the bookcases away from the doorway or anchor them to the supporting floor or adjacent wall.		
6	Computer monitor	04-N3	1	each	H	H	L	NE	Equipment stored less than four feet above the floor, like this computer monitor, is not a significant life safety hazard. However consideration should be made to securing these types of equipment to the desk top or adjacent wall.		
82	Bookcase	02-12 South Elevation	3	each	H	M	M	NE	Tall shelving or bookcases that have width to height ratios greater than four should be attached to the supporting floor or adjacent wall.		
182	Unreinforced Masonry parapet		50	LF	H	H	L	ER			
13	File cabinets	04-W4	3	each	M	M	M	NE	These flat files are three individual units stacked on top of each other. Without lateral restraints, they can easily slide off each other.		
16	Hot water heater	04-W7	1	each	M	H	L	PR	Gas hot water heaters should be anchored to the floor or adjacent wall to prevent tipping and damage to water and gas lines.		
65	Vending machine	02-15	1	each	M	M	L	NE			
83	Suspended ceiling	02-12	150	SF	M	M	M	PR	The suspended ceiling tiles are supported vertically to the roof structure. There are no lateral tie wires to compensate for lateral loads due to seismicity.		
85	Natural gas supply line	02 North Elevation	200	each	M	M	M	ER	Each gas line that enters the building should have an automatic shutoff valve to prevent escaping gas from feeding a potential fire.		
138	Credenza	04-N4	1	each	M	M	L	NE	The credenza should be anchored to the desk top or adjacent wall to prevent a potential falling hazard.		
63	Computer cabinet	02-14a	1	each	L	H	M	NE	Computer hub should be anchored to the floor or adjacent wall to limit potential damage.		
86	Communication hub	04-W8	1	each	L	L	L	NE	The communication equipment should be stored inside of protective cabinets to prevent potential damage from falling debris.		
178	Desktop computer with monitor	04-E110	2	each	L	M	L	NE	Computers could be placed on the floor to limit potential damage to stored data or the computer's electrical components. The monitor should also be anchored to the desk.		

Figure 3.1.1-1 Sample nonstructural inventory form (from Appendix C).

Appendix D, Checklist of Nonstructural Earthquake Hazards, shown in Figure 3.1.1-2 is a checklist with questions designed to help identify vulnerable nonstructural items and potential hazards associated with each item. The checklist should be carried during the field survey to help identify vulnerable items. The questions on the checklist are all stated in such a way that a "Noncompliance (NC)" answer is indicative of a potential problem. Each nonstructural component with a potential problem should be listed as a line item on the nonstructural inventory form of Appendix C showing the location and quantity of the item with any relevant comments. If an example is available for this item in Chapter 6, it may be helpful to note the detail type and example number for future reference.

6.3 Architectural Components							
Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
6.3.1	Exterior Wall Components						<i>[Exterior falling hazards are a primary concern, especially items situated above 10 feet and items that may fall over exits, walkways, or sidewalks.]</i>
	Adhered veneer	Falling hazard	6.3.1.1				Is the adhered veneer adequately attached to the structure? [This includes relatively thin sections of tile, masonry, stone, terra cotta, ceramic tile, glass mosaic units, stucco, or similar materials attached to a structural wall or framework by means of an adhesive].
							Based on visual observations and/or tapping, is the veneer free of cracked or loose sections that may fall during an earthquake?
	Anchored veneer	Falling hazard	6.3.1.2				Is the anchored veneer adequately attached to the structure? [This includes thicker masonry, stone, or stone slab units that are attached to the structure by mechanical anchors].
							Is the masonry or other veneer supported by shelf angles or other elements at each floor?
							Is the masonry or other veneer connected to a structural back-up wall at adequate spacing?
							Has the veneer been adequately maintained? Are the anchors in good condition, free of significant corrosion, and inspected regularly?

Figure 3.1.1-2 Sample checklist questions from Appendix D.

Appendix E, Nonstructural Seismic Risk Ratings, summarizes estimated seismic risk ratings stated as Low, Medium, and High for many common components based on their exposure to Low, Moderate or High levels of shaking intensity map in Figure 3.2.1–1. The risk ratings are based on the risk to Life Safety, Property Loss and Functional Loss for unanchored or unbraced items located at or near the base of a low-rise building of ordinary occupancy. The risk ratings are further explained in Section 3.2.2 and in the introduction to Appendix E. A sample of the risk ratings in Appendix E is shown below.

6.3	Architectural Components					
Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.3.1	Exterior Wall Components					
6.3.1.1	Adhered veneer	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.3.1.2	Anchored veneer	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.3.1.3	Prefabricated panels	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	

Figure 3.1.1-3 Sample risk ratings from Appendix E.

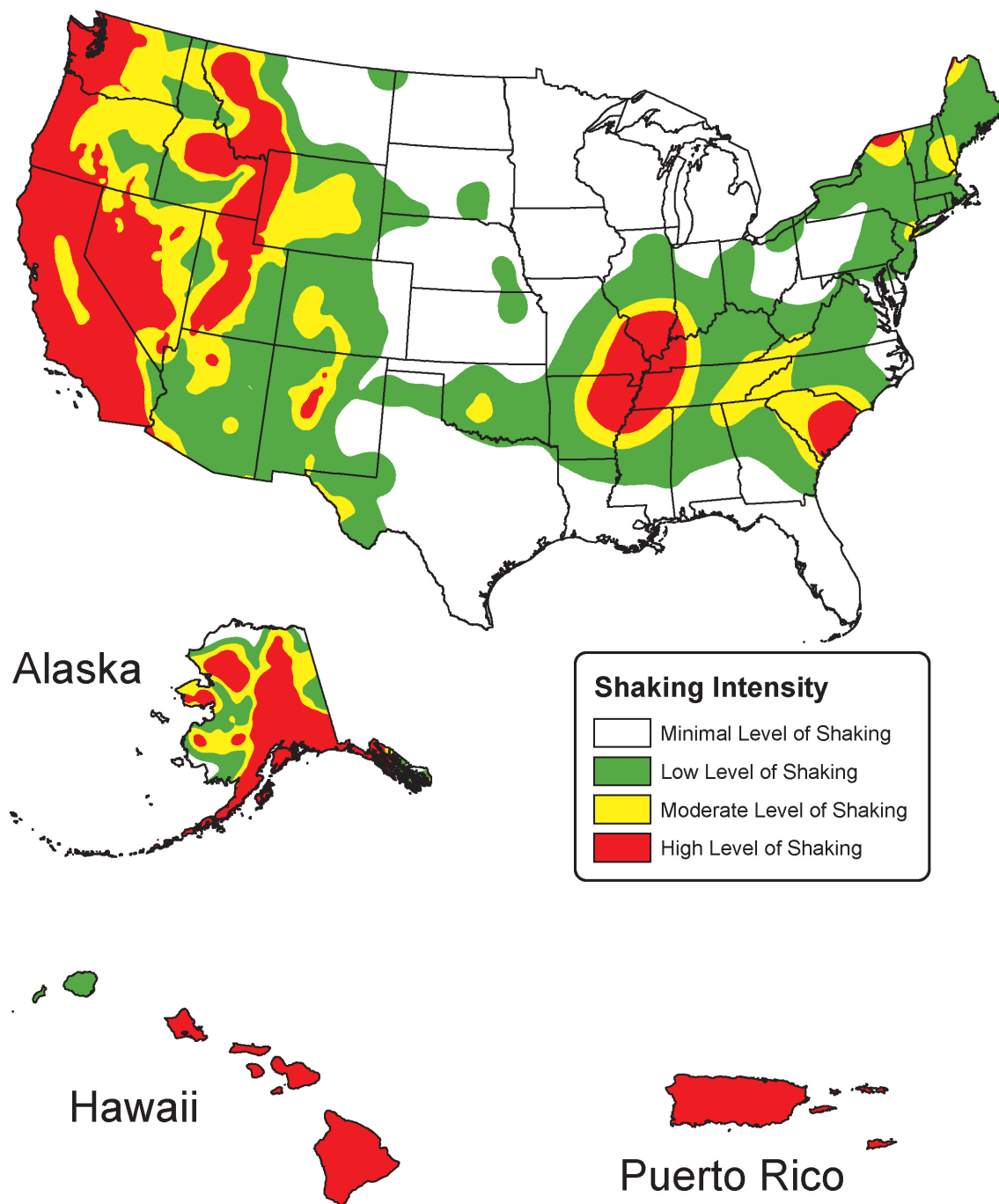
3.2 ESTIMATING SEISMIC RISK

There are two aspects of the estimated seismic risk for a given item:

- What is the seismic shaking intensity that can be expected at the site?
- For a given level of shaking, what is the seismic risk rating of a given nonstructural item in terms of life safety, property loss, and functional loss?

3.2.1 ESTIMATING SEISMIC SHAKING INTENSITY

Estimating site specific seismic hazards can be a difficult technical problem, requiring many factors to be taken into account. For the purposes of this nonstructural survey, the shaking intensity is based solely on regional seismicity. For a particular geographic location in the United States, the shaking intensity may be estimated by using the map in Figure 3.2.1–1 that shows the areas that are likely to experience minimal, low, moderate, or high levels of ground shaking during future probable maximum considered earthquake events. The ground shaking has been estimated for a stiff soil site. The information in Figure 3.2.1–1 may be summarized as follows:



The above figure was prepared by Ken Rukstales of the USGS and is based on the Figure R301.2(2) that was developed by the USGS for the 2006 International Residential Code where the Minimal Level = SDC A, Low Level = SDC B, Moderate Level = SDC C and the High Level = SDC D. Figure R301.2(2) was based on the MCE Design Value Maps prepared by the USGS for the 2003 NEHRP Recommended Provisions and presumes that the site soil classification is Site Class D and structure has Normal Occupancy (II).

Figure 3.2.1-1 Map of probable shaking intensity in the United States.

- High level of shaking: Most of California and Nevada; significant portions of Alaska, Washington, Oregon, Montana, Wyoming, Idaho, and Utah; the areas near New Madrid, Missouri and Charleston, South Carolina; small pocket areas in Arizona, New Mexico, upper New York, and upper Maine; the islands of Hawaii, Puerto Rico, and Guam (not shown).
- Moderate level of shaking: Areas adjacent to the areas of high shaking plus pocket areas in New England, New Mexico, Arizona, West Texas, Colorado, and Oklahoma.
- Low level of shaking: A portion of the western States, a significant portion of the central region of the continental United States east of the Rockies and most of New England.
- Minimal level of shaking: Remaining portions of mid-western, southern continental United States.

Shaking intensity estimates based on the probable shaking intensity map in Figure 3.2.1–1 should be adequate for evaluating components situated at or near the ground in simple, nonessential facilities. For other situations, it may be advisable to choose the next higher shaking intensity or to seek the advice of professional consultants. Note that in areas with minimal shaking, upgrade of nonstructural components generally would not be warranted unless an owner is particularly risk averse or special circumstances exist; the current code would not require many of the protective measures recommended herein, even for new construction.

Engineering Design Forces

Estimating the earthquake forces acting on a particular item in a particular building can be a difficult technical problem. In order to perform engineering calculations, an engineer may have to consider the following factors:

- the proximity of the building site to an active fault
- soil conditions at the site (other than stiff soil)
- the flexibility of the building structure
- the location of the item in the building
- the flexibility of the floor framing or walls in the immediate vicinity of the item
- the flexibility and strength of the item and its attachments
- the weight and configuration of the item
- the characteristics of any connection details between the item and the structure
- the expected relative displacement between two connection points in adjacent stories or across a seismic gap
- the function of the item
- the function of the facility

Refer to the current International Building Code (IBC) and ASCE/SEI 7 for seismic design requirements for nonstructural components and ASCE/SEI 41 for existing construction.

One reason why the use of professional consultants is recommended for complex facilities is that the generalized shaking intensity map does not take many engineering factors into consideration (see sidebar). Clearly, the complexity and detail of engineering calculations should commensurate with the complexity and importance of the facility and the item in question. It should be noted that current design codes and standards such as the *International Building Code*, *ASCE/SEI 7 Minimum Design Loads for Buildings and Other Structures*, and *ASCE/SEI 41 Seismic Rehabilitation of Existing Buildings*, reference detailed digitized seismic maps of the United States prepared by the U.S. Geological Survey (USGS). These maps consider locations and seismic activity of all known seismic sources and faults which may affect a given site, and the standards provide procedures for adjusting the mapped ground motions for site soil conditions. For designs requiring compliance with building code or national standard requirements, the maps referenced by the code or standard in effect at the time must be used to establish minimum criteria.

In addition, it may be appropriate to consider more than one earthquake scenario for a particular facility, since earthquakes of different magnitudes may occur at different average time intervals. For some facilities, it may be useful to evaluate more probable frequent events, such as those that are likely to occur every 100 years. While new construction projects have to anticipate the most severe shaking, others who are doing voluntary retrofits may find it more economical to plan for a smaller, more frequent event.

3.2.2 ESTIMATING SEISMIC RISK RATINGS

The risk ratings provided in Appendix E are based on a review of damage to nonstructural components in past earthquakes and on the judgment of the authors and their advisory panel. Estimates of future earthquake damage to either the structural or nonstructural components of a building are only that—estimates—and should be used with discretion. The approximations provided in this guide are adequate for the purpose of making an initial determination of the seismic risk of the nonstructural components of a simple facility. For a facility that is more complex, or for one where the potential risk is high, more detailed analyses should be performed by an in-house engineer or a professional consultant. In this document, the seismic risks for life safety, property loss, and functional loss have been rated simply as high, medium, or low for different levels of shaking intensity. Note that these ratings refer to primary losses caused by damage to the item in question; potential consequences or secondary losses are not considered. Appendix E contains more detailed notes concerning the definitions and assumptions used in assigning risk ratings. Stated briefly:

- Life Safety risk is the risk of direct injury by the item.
- Property Loss risk is the risk of incurring a cost to repair or replace the item as a result of damage incurred.
- Functional Loss risk is the risk that the item will not function as a result of the damage incurred.

The estimated risk ratings shown in Appendix E assume that the item is unbraced and unanchored and are intended for buildings with ordinary occupancies, not for essential facilities. The primary purpose of this information is to assist in assigning priority ratings, described below, and to help in identifying the most critical hazards.

3.2.3 ASSIGNING PRIORITY RATINGS

Prioritization may be based on budget constraints, risk considerations (i.e., those elements that pose the greatest risks to safety, property or function are retrofitted first), availability of unoccupied space, or to achieve the highest cost to benefit ratio.

A simplified priority rating system might be used to indicate which items are more vulnerable to earthquake damage and to indicate those items whose failure is most likely to have serious consequences. All components could be assigned a high, medium, or low priority, or each item or type of item could be ranked in order from highest to lowest. The highest priority might be assigned to those components for which all three risk ratings are high. If loss of function is not a serious concern, then the highest priority might be assigned to items for which the life safety risk is high and the upgrade cost is lowest, since these hazards could be reduced most cost-effectively. The assignment of priorities may vary widely for different types of facilities, and this document merely provides some guidelines that can be used to establish a ranking system. In assigning the rating priorities, the requirements for new construction should be considered. If it is not required for new construction, then it does not make much sense to do a seismic retrofit of that item in an existing facility.

3.2.4 APPLICATION OF NONSTRUCTURAL GUIDELINES

When estimating seismic risk and assigning priority ratings, it should be noted that current building codes and seismic design standards for new construction do not require seismic design of anchorage and bracing for nonstructural components in every part of the United States.

- In areas denoted as experiencing minimal levels of seismic shaking intensity in Figure 3.2.1-1, no seismic anchorage or bracing of nonstructural components is required.
- For most buildings in areas denoted as experiencing low levels of seismic shaking intensity, only parapets are required to be braced. For essential facilities, all architectural components are required to be anchored and braced.
- In areas denoted as experiencing moderate levels of seismic shaking, all architectural components are required to be anchored and braced. However, in most buildings, electrical and mechanical components and systems do not require anchorage and bracing. For essential facilities, mechanical and electrical components are required to be braced.
- In general, in areas denoted as experiencing high levels of seismic shaking intensity, all architectural, mechanical, and electrical components are required to be anchored and braced in all buildings.

In addition, current seismic codes and standards also exempt mechanical and electrical components from bracing or anchoring, regardless of seismic area, in nonessential facilities, if they weigh less than 400 pounds and are mounted at a height 4 feet or less above the floor or, if elevated, weigh less than 20 pounds. Distributed systems in nonessential facilities, such as piping or HVAC ducting, are also exempt from bracing or anchoring if they weigh less than 5 pounds per lineal foot and are provided with flexible connections.

Current seismic codes and standards do not provide much guidance on when seismic anchorage and bracing are required for contents except for cabinets and computer access floors which are treated as architectural components. The reason why they are typically not treated in standards for new construction is that furniture, fixture, equipment and contents are usually installed after the building has been approved for occupancy by the building official; thus, the building official no longer has any control over the installation after occupancy approval has been given.

4. NONSTRUCTURAL RISK REDUCTION FOR EXISTING BUILDINGS

Nonstructural risk reduction programs may vary depending on whether the nonstructural components in question are in an existing building, a historic facility, an essential facility, a facility containing hazardous materials, or are planned for a new building. The current chapter addresses issues related to existing buildings; Chapter 5 addresses issues related to new construction. Portions of these chapters are written in parallel, yet they are unique to each chapter. If portions apply to either situation, they appear only once. For instance, the material on implementation strategies appears only in Chapter 4; the material on current code requirements and code enforcement appears only in Chapter 5.

There is considerable overlap between the *new* and *existing* building categories. For instance, if an existing building undergoes a major alteration and changes to a higher use category, then it would be required to comply with current codes in many jurisdictions and thus, the project requirements would closely resemble those for new construction. Conversely, a new building becomes an existing building as soon as the occupancy permit is issued. Thus, tenant improvements and the installation of furniture, fixtures, equipment, and contents for the first occupants of a leased portion of a new building often take place after the original design team is finished and the major architectural, mechanical, electrical, and plumbing components are installed; for this reason, many of the problems involved in coordinating the anchorage of the tenants' components with preexisting components are the same as for a project in an older existing building.

Historic buildings, essential buildings such as police and fire stations, or facilities that handle hazardous materials have special requirements, which are typically more complex than those for ordinary occupancies. While some issues related to these types of facilities are mentioned here, the treatment of nonstructural components in these facilities is beyond the scope of this guide. The list of references and additional sources of information may help to address these issues for specialized facilities.

4.1 PROGRAM OBJECTIVES AND SCOPE

Several recent earthquakes in the United States have provided evidence suggesting that nonstructural damage may account for more than 50% of total damage in future domestic earthquakes. As advances are made in the structural design of buildings, and we experience fewer structural failures and fewer collapses as a result, the significance of nonstructural damage becomes more apparent. In addition, postearthquake operations are of increasing concern not only to essential facilities such as police and fire stations and hospitals, but also to manufacturing facilities, banks, mobile phone providers, and many other businesses concerned with loss of revenue or loss of market share that would result from a lengthy outage following an earthquake. Organizations and owners who want to reduce their seismic exposure will need to address the nonstructural hazards in their facilities.

Seismic improvements to existing buildings might be mandated by a governmental body or might be motivated by a desire to provide for postearthquake operations, to reduce future losses or liability, to reduce insurance premiums, or to increase the resale value of the property. In most cases, seismic improvements to existing facilities are undertaken on a voluntary basis and, as a result, organizations and owners have latitude in setting the objectives and defining the scope of a nonstructural risk reduction program for existing buildings.

4.1.1 VOLUNTARY VS. MANDATORY RISK REDUCTION

In general, a nonstructural risk reduction program for existing buildings would be considered a voluntary upgrade; that is, a program that is voluntarily undertaken by an owner to reduce the potential liability and losses in the event of an earthquake. Although current codes have requirements for bracing and anchorage of nonstructural items, most jurisdictions do not currently require nonstructural hazards to be addressed retroactively in existing facilities.

There are some notable exceptions, in cases where a jurisdiction may require mandatory retrofitting of existing nonstructural components. A few of these are listed below:

- Many jurisdictions in California have ordinances requiring that unreinforced masonry parapets, particularly those adjacent to a public right-of-way, be braced or anchored to prevent collapse in an earthquake.
- Some major cities including Chicago, New York, Boston, and Detroit have façade ordinances that mandate periodic inspection of building façades; while this is not intended as a seismic requirement, it has the benefit that the architectural cladding, veneer, ornamentation, and anchors are inspected and maintained on a regular basis.

- Seismic safety legislation (SB 1953) was passed in California in 1994, following the Northridge Earthquake. That earthquake resulted in the suspension of some or all services at 23 hospitals and in \$3 billion in hospital-related damages. This legislation requires California hospitals to comply with specific nonstructural hazard mitigation deadlines, including: (1) major nonstructural items including emergency power supply, bulk medical gas systems, communication systems, fire alarm systems and exit lighting are to be braced by 2002; (2) most nonstructural items within “critical care areas” are to be braced by 2008; and (3) most nonstructural components within the hospital are to be braced by 2030. This is an unfunded mandate; the burden of financing these improvements rests with the health care providers.
- Major alterations, additions, or changes of use may trigger code requirements to bring existing construction, including the nonstructural items, into compliance with the current code. For instance, conversion of a warehouse to a school building would trigger requirements for current code compliance in many jurisdictions; check for local requirements and exemptions.

The rules that apply for voluntary upgrades to existing facilities are typically different than those that apply to new construction or to mandatory upgrades. While it may be desirable to design the nonstructural anchorage details for existing equipment in existing buildings using the current code, it is not typically required for voluntary upgrades. In order to describe the spectrum of risk reduction objectives, it is useful to introduce some performance-based design concepts.

4.1.2 PERFORMANCE-BASED DESIGN CONCEPTS

The use of performance-based design concepts requires a discussion between building design professionals and their clients about performance expectations and seismic risk tolerance. Performance-based design provides terminology to characterize seismic risk and seismic performance and provides a framework for making comparisons between varying levels of seismic hazard, structural and nonstructural performance, postearthquake functionality, acceptable and unacceptable damage, and total earthquake losses over the expected life of the facility. Design professionals, organizational risk managers, building owners, business owners, and tenants all need to have an understanding of the tradeoffs between risk and reward; an understanding that seismic design and investment choices have a relationship to expected future performance and potential future losses. The parties all need to understand that they make choices, both passive and active, based on their understanding of the issues and their

seismic risk tolerance. One may choose to live with known seismic risks or choose to initiate programs to reduce some or all of the known hazards; either way, a choice must to be made.

Performance-based design concepts have been in development for several decades; this process is ongoing. These concepts are gradually finding their way into the building codes used for new construction, such as the *International Building Code* and ASCE/SEI 7 *Minimum Design Loads for Buildings and Other Structures*, and into the building standards used for the evaluation and retrofitting of existing structures, ASCE/SEI 31 *Seismic Evaluation of Existing Buildings* and ASCE/SEI 41 *Seismic Rehabilitation of Existing Buildings*, respectively. Previous editions of U.S. building codes were based on the philosophy that structures should not collapse in a major earthquake but might suffer severe structural and nonstructural damage; this was a minimum life safety standard and is roughly comparable to the Basic Safety Objective that is now described in ASCE/SEI 41–06 (ASCE, 2006). Although engineers were aware that a “code design” was only meeting minimum standards, it is not clear that building owners and occupants had a similar understanding. What is significant about performance-based design concepts is that they are used to describe a range of objectives and that they make the choice of performance objectives an explicit part of the design process; the design professional and the client need to discuss and agree on those performance objectives.

While it is not relevant to describe the engineering design process of ASCE/SEI 41–06 in detail here, it is relevant to describe the decision making process used to determine the scope and desired performance objectives for a voluntary upgrade. Note that in addition to the Basic Safety Objective, the standard provides guidance on choosing objectives for voluntary upgrades that are both more ambitious, “Enhanced,” and less ambitious, “Limited,” than the Basic Safety Objective. The choice of objective will determine which hazards are addressed, what

Analogy: Financial Risk Tolerance

One of the first things most financial advisors do with new clients is to present them with an investment questionnaire to gauge how they feel about risking their money; that is, to assess what is referred to as their “investment risk tolerance.” The investment advisor cannot make reasonable recommendations on how to allocate the client’s assets without knowing something about their tolerance for financial risk. Is the investor conservative, moderate, or aggressive? Given the tradeoffs between risk and reward, do they have a low, medium, or high tolerance for financial risk?

performance is likely following a major earthquake, and how much structural and nonstructural damage the facility is likely to sustain.

Several key questions as posed in ASCE/SEI 41–06 are listed below. The array of performance options described in ASCE/SEI 41–06 is shown in Table 4.1.2–1:

- What are the retrofitting objectives?
- What earthquake scenario(s) are most relevant for this facility?
- What kind of postearthquake functionality is required for this facility?
- What target structural performance level is required for this facility?
- What target nonstructural performance level is required for the facility?
- What target building performance level is required for the facility, and how does that relate to the target levels of structural and nonstructural performance and to the expected postearthquake damage state for the facility?
- What combination of choices meet the ASCE/SEI 41–06 Basic Safety Objectives? Enhanced Objectives? Limited Objectives?

Table 4.1.2–1 Target Building Performance Levels (after ASCE/SEI 41–06)

Target Building Performance Level	Expected Postearthquake Damage State	Target Structural Performance Level	Target Nonstructural Performance Level
Operational Level	Backup utility services maintain function; very little structural or nonstructural damage	Immediate Occupancy	Operational
Immediate Occupancy	The building remains safe to occupy; any structural or nonstructural repairs are minor	Immediate Occupancy	Immediate Occupancy
Intermediate Level		Damage Control	
Life Safety	Structure remains stable and has significant reserve capacity; hazardous nonstructural damage is controlled	Life Safety	Life Safety
Intermediate Level		Limited Safety	Hazards Reduced
Collapse Prevention	The building remains standing, but only barely; the building may have severe structural and nonstructural damage	Collapse Prevention	Not Considered

According to ASCE/SEI 41–06, the Basic Safety Objective is achieved by the following combination:

- Design for *Life Safety Building Performance* for Basic Safety Earthquake 1 (earthquake that occurs every 500 years), AND
- Design for *Collapse Prevention Building Performance* for Basic Safety Earthquake 2 (earthquake that occurs every 2500 years).

All other combinations of performance levels and seismic hazard levels are characterized as either Limited or Enhanced objectives (for more on this, see sidebar at right).

As seen in Table 4.1.2–1, an effort to preserve postearthquake operations at either the *Immediate Occupancy* level or the *Operational* levels require that both structural and nonstructural hazards be addressed. Indeed, the higher *Operational* standard for nonstructural components is what differentiates these two enhanced levels of building performance. Per ASCE/SEI 41–06, the differences in design between the different target levels of building performance are higher or lower seismic design forces and explicit design for more or fewer nonstructural components. Engineering analysis methods, such

Limited and Enhanced Rehabilitation Objectives per ASCE/SEI 41–06

Besides the stated requirements for the Basic Safety Objective, all other combinations of performance levels and seismic hazard levels are characterized as either Enhanced or Limited objectives. In comparison with the Basic Safety Objective, a higher performance level correlates with less damage, lower losses, and increased functionality, whereas a lower performance level correlates with more damage, higher losses, and reduced functionality. The following are examples of Limited Rehabilitation Objectives:

- Address only serious nonstructural falling hazards considering a small, frequent seismic event, i.e., according to ASCE/SEI 41–06 terminology, target for a *Hazards Reduced* nonstructural performance level, considering the 50%/50 year event.
- Address all nonstructural life safety hazards without consideration of structural hazards, i.e., according to ASCE/SEI 41–06 terminology, target for a *Life Safety* nonstructural performance level for any chosen earthquake scenario.

In contrast, the following is an example for an Enhanced Rehabilitation Objective:

- Provide reduced damage and increased functionality, i.e., according to ASCE/SEI 41–06 terminology, design for *Immediate Occupancy* Building Performance for any earthquake hazard level. Note that to achieve this performance level, both structural and nonstructural upgrades may be required.

as nonlinear analysis or the push-over method, are available and can be used to check whether or not the design meets the target performance objectives. There are many other questions that may help refine the project objectives and scope of work, such as:

- What kind of losses can the business or organization tolerate after an earthquake?
- How much downtime can the organization tolerate before employees, clients, or customers go elsewhere?
- Does the organization have earthquake insurance? If so, how much of the losses are covered? What are the deductibles? What is the cost-benefit ratio of doing upgrades versus providing coverage and suffering a loss?
- Is this a historic building, essential facility, or facility with specialized or unique considerations?
- What nonstructural components are under your direct control? Architectural? Mechanical, electrical, and plumbing (MEP)? Furniture, fixtures, equipment (FF&E)? Contents? Or all of these?
- Will the project include upgrades to only MEP and architectural components, or will FF&E and contents be included as well?
- What are the most hazardous nonstructural components?
- For leased facilities, which elements are responsibilities of the owner and which are responsibilities of the occupants?
- If the owner has undertaken any seismic upgrades, is there a report available describing the project objectives or design level? Were nonstructural items addressed?
- Are there any incentives a lessee can offer a building owner to improve the safety of leased space?
- Do you need to consider relocation to another space that provides an increased level of seismic safety?

The point of including this discussion is not to discourage the reader by presenting the design process as a complex system, tempting the reader to conclude that it would be much easier to do nothing. The point of the discussion is to emphasize that choices need to be made in deciding how to manage seismic risk. Resources are always limited, and seismic risks must be balanced against many other types of risk. Whatever seismic hazard reduction objectives are selected, they should be chosen with an understanding of the risks and rewards. A decision to mitigate known seismic hazards, particularly dangerous life safety hazards, would generally be considered both reasonable and prudent, even if it were not mandated by law. A decision to upgrade a complex facility to *Immediate Occupancy* or *Operational* performance level is a major and complex undertaking, since facility operations may depend on the continued function of

hundreds or thousands of individual nonstructural components. Such an upgrade should not be undertaken without an understanding of the costs and benefits of such a program.

4.1.3 LEGAL CONSIDERATIONS

A common concern voiced by building owners who are considering seismic improvement projects for their building or its nonstructural contents and components is the question of legal liability. A persistent belief is that one should not do anything, because if a life safety issue is uncovered and is made known to the owner, then the owner may be liable for any injuries or deaths that arise due to a severe earthquake damaging their building. This “ignorance is bliss” approach is not supported by legal precedents.

The legal issues involved are not black and white and may depend on the type of the facility, the sophistication of the owner, and the number of occupants at risk. There are two ways of looking at these issues:

- One view is that the standard of care of any owner is to act reasonably and to exercise ordinary care in managing the property. This care includes inspecting and maintaining owned buildings in a safe condition. Safety is usually measured against the building standard in effect at the time when the building was constructed, not the current code or any current evaluation standard for existing buildings. Therefore, if owners choose to evaluate their building using a more modern standard and uncover issues in doing so, it is then at their discretion on how, when, and if to act on these data in a voluntary manner.
- Another view is that if an owner is aware of a dangerous condition on their property, they have an affirmative duty to warn those affected or to mitigate the hazard.

If an owner does undertake a project or program to study and possibly to improve the seismic performance of a building or a building’s nonstructural components, then the following is recommended to provide transparency:

- Ensure that any inspection is conducted by competent, qualified, and experienced parties
- Use widely accepted inspection, design, and construction standards such as those from FEMA, ASCE or other national or internationally recognized standard organizations
- Develop clear and complete documentation of decisions and actions
- Establish processes to ensure that all work is performed properly
- Implement any remedial actions through experienced contractors

- Proceed without creating any dangerous conditions and without making the building performance worse than it was before
- Proceed in a reasonable and responsible manner

The position of the authors is that an owner is much better off being proactive and doing something to investigate or improve the performance of a building and its nonstructural components and contents than doing nothing. Ultimately, however, an owner's decision to undertake such a remediation project is his or hers alone, and many considerations, such as public relations, risk tolerance, affordability, and market conditions will undoubtedly be factored into the decision.

It is recommended that an owner concerned with these issues seek appropriate legal counsel with expertise in construction law and seismic mitigation issues, to assist in their decision making process.

4.2 DESIGN CONSIDERATIONS

The selection of design solutions must be consistent with the scope and objectives selected for the project. Some design solutions can be implemented without consideration of the building code and without engineering expertise. Other design solutions rely on building codes and standards, such as ASCE/SEI 7-10, ASCE/SEI 31-03, and ASCE/SEI 41-06, that all contain elements of the performance-based design methods discussed above. If engineering consultants are engaged to provide design solutions, the selection of seismic force levels, design coefficients, and design methods depends upon the performance objectives selected.

Specific design solutions for nonstructural items fall into three broad categories:

NON-ENGINEERED (NE): These are typically simple, generic details or common sense measures that can be implemented by a handy worker or maintenance personnel using standard items from any hardware store. Many of these solutions apply to contents that are not directly covered by building code provisions. As an example, Chapter 6 contains a detail showing the general configuration for anchoring a bookcase to a stud wall (see Figure 6.5.2.1-4) and identifies the parts needed but does not explicitly indicate the size of the angle bracket or screws needed; this is left to the handy worker based on the size and weight of the particular bookcase and the type and spacing of studs. Some of these types of solutions have failed in past earthquakes, usually due to undersized bolts and hardware or because bolts have failed to engage a structural member. As a result,

non-engineered solutions are generally not appropriate for hospitals or other facilities that have chosen operational functionality as a performance level objective.

PRESCRIPTIVE (PR): Prescriptive design details are available in the public domain that have been engineered to meet or exceed code requirements for a set of common conditions and can be used directly in many situations. One prescriptive detail included in Chapter 6 is the anchorage detail for a residential or small commercial water heater (see Figure 6.4.2.4–6). This detail is applicable for the anchorage of a water heater, up to 100 gallons, attached to a wood stud wall. The detail calls out the required hardware and the size and spacing of fasteners.

While there are only a limited number of these details currently available, we anticipate that more such details will be developed as engineers, architects, and specialty contractors become more familiar with the new code requirements for nonstructural components. Some of the prescriptive details have been developed by or for the Office of Statewide Health Planning and Development (OSHPD), the entity in California responsible for overseeing hospital design.

ENGINEERING REQUIRED (ER): These are nonstructural anchorage details specifically developed by a design professional on a case-by-case basis for a specific set of conditions. First, the owner and design professional need to agree on the desired level of protection for the anticipated level of shaking, only then can the design professional develop details consistent with the objectives. Design methods and design coefficients are selected based on the performance objectives as discussed above. An anchorage detail designed for a lateral force of 1.0 g will generally be more robust and more costly than one designed for a lateral force of 0.1g. Higher design forces and more complex engineering methods may be required to meet higher performance objectives.

As part of the design process, it may be important to consider a number of issues:

- **Interaction of nonstructural components.** Many nonstructural systems are interconnected or interdependent; items in close proximity can impact one another and tall or overhead items can fall and damage items below. Lights, ceilings, diffusers, ducts, piping, sprinkler heads, and variable air volume boxes may all share the plenum space above the ceiling and it may be challenging to find ways to keep them separated and to provide independent support for all of them.
- **Interaction of nonstructural and structural components.** Nonstructural components may be damaged by the deformations of structural components. Items that cross seismic

separations between buildings, connect at adjacent floor levels, or are located in base isolated structures have special design considerations based on the expected deformations of the structural system.

- **Strength of structural components.** Since nonstructural components typically anchor to structural slabs, walls, and framing, it is important that the capacity of these components be checked for adequacy when tall and heavy items are being anchored to them.
- **Location.** Design forces are typically higher for items located in mid- and high-rise buildings and on roofs. The location of the item in the building may influence the design.
- **Primary vs. secondary effects of failure.** If failure of an item may result in the release of water or hazardous materials such as toxins, chemicals, or asbestos, it may warrant additional attention to address these damaging secondary effects.
- **System performance.** Fire protection systems, emergency power generation systems, and computer and communication networks are systems that depend on the functionality of multiple components; the failure of any part might compromise the functionality of the system. All related components must be checked if the system is required for functionality.
- **Emergency egress.** Items located over exits, in stairways, and along exit corridors may warrant special attention in order to ensure the safe exit of building occupants.

4.3 PROJECT PLANNING AND IMPLEMENTATION STRATEGIES

There are a number of options to consider in implementing a program to reduce the vulnerability of nonstructural components. As described above, one of the critical first steps is to define the project objectives with a clear understanding of what these basic, enhanced, or limited objectives will mean in terms of the expected performance of the facility and amount of structural and nonstructural damage that is expected to occur for a given level of shaking.

It is important to understand at the outset the level of commitment that is required from the organization in order to achieve the desired objectives. In order to achieve the *Hazards Reduced* nonstructural performance level, the bracing or anchoring of several obvious nonstructural falling hazards at a small commercial location may be accomplished by a skilled laborer over several weekends without any employee involvement. On the other hand, achieving the enhanced objectives which would allow for *Immediate Occupancy* or *Operational* performance levels requires a major commitment from the top down in an organization. Achieving a level of readiness that will allow a facility to remain fully operational will likely require both structural and nonstructural upgrades and a commitment of capital, both initial and ongoing; time for employee training; downtime for implementation; incorporation with purchasing, operations, maintenance, facilities, and clear assignment of responsibilities for implementation and ongoing program maintenance.

Additional References for Architects and Engineers

FEMA has published a series of guides addressing the incremental seismic rehabilitation of various types of facilities, including the related nonstructural components, as follows:

FEMA 395	Schools (FEMA, 2003)
FEMA 396	Hospitals (FEMA, 2003)
FEMA 397	Offices (FEMA, 2003)
FEMA 398	Multifamily Apartment Buildings (FEMA, 2004)
FEMA 399	Retail Buildings (FEMA, 2004)
FEMA 400	Hotel and Motel Buildings (FEMA, 2004)

It is also important that someone at the planning stage takes a broad view of what is proposed. A facility survey will identify the items and areas of the facility that will be affected. As the objective is to improve seismic safety, it is important to also take note of existing seismic protections and see that these components are not compromised. It may be necessary to evaluate the strength of existing partition walls and floor or roof framing to see that these components have sufficient capacity to support the nonstructural items to be anchored. In some cases, structural components may need strengthening in order to support the loads from the nonstructural components.

Once the project objectives are defined, there are a range of different strategies that can be used for implementation. Installation of protective measures can be done immediately, in phases, as part of routine maintenance or scheduled remodeling. A comparison of preliminary

cost estimates and schedules for several different implementation strategies consistent with the project objectives may help in deciding which implementation strategy will work best.

4.3.1 INTEGRATION WITH MAINTENANCE PROGRAMS

One of the easier means of gradually implementing earthquake protection in an existing building is to train maintenance personnel to identify and to properly mitigate nonstructural hazards that they may discover as they survey the building for other purposes or to mitigate problems identified by an outside consultant engineer. The disadvantages of this approach are that protection is increased only gradually and the potential cost savings from doing several related projects at the same time may be lost.

Once nonstructural bracing and anchorage are installed, maintenance personnel should be trained to inspect and monitor the installations and be responsible for the upkeep of the protective measures where appropriate. For facilities with specialized equipment, this maintenance function must be performed by someone familiar with the equipment to ensure that the protective measures are installed and maintained without compromising the equipment functionality.

4.3.2 INTEGRATION WITH REMODELING

If there are other reasons for remodeling, there may be an opportunity to increase the protection of several nonstructural components at the same time, especially ceilings, partitions, windows, piping, and other built-in features. If an architect, interior designer, or contractor is handling the remodeling, the possibility of incorporating additional earthquake protection into the space should be discussed, and a structural engineer's expertise should be employed where indicated. Newly installed components will need to comply with current code requirements. Depending on the scope, the remodel may also trigger requirements to bring some existing components of the facility into compliance with current code; check the requirements for additions and alterations with the local jurisdiction.

A word of caution: In some cases, remodeling efforts have reduced rather than increased the level of earthquake protection through the accidental modification of components that originally received some seismic protection as a result of the input of a structural engineer or architect. It is important not to compromise existing seismic protections; it is also important not to overload partition walls, floor or roof framing, or an existing ceiling grid by using them to brace or anchor items that are too heavy. In some instances, the remodeling scope may

need to be extended to include ceilings, partitions, or structural components so that the strength of these components can be upgraded to support additional loading.

4.3.3 PHASED OR INCREMENTAL UPGRADING

In some cases, it may be possible to upgrade different areas within a building at different times or to select one or more types of nonstructural components throughout a building and upgrade them at the same time. Some projects can be completed in a weekend, making it possible to upgrade equipment or other items without interrupting the normal work flow. Companies with annual shutdown periods may find it wise to upgrade the highest-priority items during each annual shutdown. Work that interrupts the use of a space, such as setting up ladders or scaffolding to work on the ceiling or ceiling-located items, could be restricted to limited areas in a facility at a given time, minimizing the overall disruption.

An all-at-once implementation process, similar to that used in new construction, can be used in existing facilities either when the extent of the work required is small or when the work is extensive but the resulting disruption is tolerable. A favorable time for this approach is when a building is temporarily vacant, such as during planned renovations.

4.3.4 INTEGRATION WITH PURCHASING

A guideline with a list of nonstructural items could be created to indicate special purchasing considerations. For example, file cabinets should have strong latches and wall or floor attachments, bookcases should have bracing and floor or wall attachments, and server racks should come with seismic detailing. Increasingly, vendors are marketing items with "seismic-resistant" details such as predrilled holes for anchorage. There are also many vendors that supply hardware and kits for seismic anchorage of equipment and furniture; these items should be stockpiled or ordered routinely along with each new equipment purchase. The effective use of these guidelines requires coordination between the purchasing and facilities or operations functions.

Integration with purchasing may be used in conjunction with any of the other strategies. If used alone, it will improve the safety of newly purchased items, but will not enhance the safety of existing items or address architectural items such as parapets, partitions, or ceilings. Over time, the safety of the facility will gradually improve as new items are purchased and existing items are replaced.

4.4 RESPONSIBILITY AND PROGRAM MANAGEMENT

4.4.1 RESPONSIBILITY

Successful implementation of a nonstructural risk reduction program may involve many steps, including integration of the risk reduction program with the overall mission or business plan and balancing the seismic risks with other risks that businesses and organizations face. Program tasks may include planning, budgeting, scheduling, allocation of in-house resources and personnel, selection of outside consultants and contractors, contract negotiation and administration, coordination of numerous trades, managing outages or disruption, facility surveys, installation, inspection, oversight, purchasing, evaluation, and ongoing maintenance of the seismic protection measures. Assigning clear responsibility for each task is important to the success of any risk reduction program. Figure 4.4.1–1 shows an example of a responsibility matrix that could be readily adapted by listing the nonstructural components for a particular project. This example format can be used to track who is responsible for design, design review, installation, and observation. If special inspection is required, this could also be added to the table. Appendix B contains templates for use in assigning responsibility for design, construction and inspection of nonstructural installations governed by ASCE/SEI 7–10. The responsibility matrices are intended to be used in conjunction with the construction specification in Appendix A.

One of the initial tasks is to assess the capabilities of in-house resources and the need for outside consultants. The answer depends on the nature of the physical conditions in the facility and the characteristics of the organization.

- In-house implementation can be adequate where the potential hazard is small or the in-house familiarity with engineering and construction is greater than average.
- Specialized consultants with experience in the evaluation and reduction of nonstructural risks may be required for essential facilities or larger and more complex facilities where the potential hazards or potential losses are high.
- Facilities with moderate risk may fall in between these two examples and use a combination of expert advice and in-house implementation. For example, after an initial survey is conducted and a report is prepared by an expert, the remainder of the implementation might be handled in-house without further assistance.

Job Aid:

Nonstructural Component Seismic Resistance Responsibility Matrix

Who is Responsible for:

Type of Nonstructural Component or System	Design	Design Review	Installation	Observation
■ Access Floor (raised)				
■ Ceilings				
Suspended T-bar				
Gypsum Board (hung)				
■ Electrical Equipment				
Busduct / Cable Trays				
Power Generator				
Light fixtures				
Main Service Panel				
Transformers				
■ Elevator				
Cable guides				
■ Escalator				
■ Exterior Cladding:				
EIFS				
GFRC				
Metal Panels				
Precast Concrete				
■ Exterior Window Walls				
■ Fire Sprinkler System				
■ Fluid Tanks				
■ Mechanical Equipment				
Air Handlers				
Boilers				
Chillers				
Cooling Tower				
Condensers				
Ductwork / VAV box				
Fans				
Furnaces				
Piping Systems				
Pumps				
■ Interior Partitions				
■ Other Equipment				
■ Stairs				
■ Storage Racks				
■ Veneer				
Brick				
Stone				
■ Water Heater				

Figure 4.4.1-1 Example responsibility matrix.

One of the larger nonstructural earthquake hazard evaluation and upgrade programs is that of the U.S. Department of Veterans Affairs (VA) for its hospitals. The typical procedure followed by the VA is to hire consultant experts to assess the seismic risk at the site, to review the facility and list specific nonstructural items that are vulnerable to future earthquakes, and to provide estimated upgrade costs and group the items by priority. Once the consultants have established the program outline, the VA maintenance staff at each hospital is given many of the implementation tasks. As mentioned in the introduction, there are limits to the self-help diagnosis and prescription approach; especially if larger buildings or more serious safety hazards, property risks, or critical functional requirements are involved, the use of consultants may be advisable.

Consultants and design professionals could be used to assist with any or all of the tasks from program planning through implementation. Outside consultants that could facilitate planning, design, and implementation may include the following:

- Risk managers
- Earthquake engineers
- Structural engineers
- Civil engineers
- Architects
- Mechanical engineers
- Electrical engineers
- Interior designers
- Specialty contractors
- Special inspectors
- Vendors of specialty hardware and seismic protection devices

Many architects and engineers are qualified to design bracing or anchorage for simple nonstructural items. However, the design of anchorage and bracing for specialized equipment or for the systems needed to maintain operations in a hospital or manufacturing facility requires specialized experience with seismic design for nonstructural components. While there currently is not a recognized professional designation for someone with this type of experience, there may be one in the future. The job requires familiarity with MEP equipment and piping, architectural components, issues such as fire protection, and requirements of the Americans with Disabilities Act, computer networks, industrial storage racks, and all the other categories of nonstructural components and contents. When selecting outside consultants, check that

they have experience with nonstructural seismic design, preferably specific experience with the type of equipment or facility in question.

4.4.2 SUSTAINING PROTECTION

On an organizational level, sustaining protection generally requires a serious commitment from management and may include development of seismic planning guidelines for the organization, development of purchasing guidelines, ongoing personnel training, periodic facility audits, and incorporation into annual staff reviews. It is sometimes more problematic to maintain the human aspects than hardware aspects of nonstructural protection. Over time, interior fastenings and restraints may be removed as people move equipment or other items and fail to reinstall the protective devices. Chains used to restrain gas cylinders or elastic shock cords on bookshelves are effective only when they are in use. This is also true of tethers on office copiers, countertop lab equipment, or vending machines. Some nonstructural protection devices, such as anchorage hardware for exterior objects, may deteriorate with time if not protected from rust. New items may be purchased and installed without seismic protection in the absence of purchasing guidelines. As noted above, remodeling projects can sometimes result in the elimination of protective features if there are no seismic guidelines.

Training is required to ensure that gas cylinders, storage rack contents, lab and office equipment, and chemicals are properly stored. Maintenance personnel may periodically survey the building to find out whether or not earthquake protection measures are still effectively protecting mechanical equipment such as emergency generators, water heaters, and specialized equipment. Additionally, supervisors can be made responsible for an annual review of their work spaces. If there is a separate facility or physical plant office in an organization, it may be a logical place for the responsibility for sustaining protection to reside. Organizations with safety departments have successfully assigned the role of overseeing nonstructural earthquake protection to this functional area.

An earthquake risk reduction program should conform to the nature of the organization. In the case of the University of California, Santa Barbara, the implementation and maintenance of a campus wide program to address nonstructural earthquake hazards was initiated by a one page policy memo from the chancellor. Each department head was made responsible for implementation of the policy, and the campus Office of Environmental Health and Safety was given the job of advising departments on implementation, making surveys, and evaluating the program's overall effectiveness (Huttenbach, 1980; Steinmetz, 1979).

4.4.3 PROGRAM EVALUATION

To assess whether the nonstructural risk reduction program was worth the cost, the strong points and deficiencies of the program need to be established. There are two program evaluation techniques to employ in accomplishing this task. The first is to ask:

- How well has the program met its stated objectives?
- Have the costs been within the budget?
- Have the tasks been completed on schedule?
- Is the scope of the effort as broad as was originally intended, or have some items been neglected that were targeted for upgrades?
- Have employee training exercises or other features of the plan all been implemented?
- How well have the measures been implemented?
- Have the upgrade details been correctly installed?
- Is the training taken seriously?
- Do we need to modify (either enhance or reduce) our objectives going forward?

The second evaluation technique is to ask:

- If the earthquake happened today, how much would the losses be reduced by due to the nonstructural protection program?
- Have the costs been worth the benefits?

4.5 COST BENCHMARKS – EXAMPLES

4.5.1 EXAMPLE 1 – MANUFACTURING FACILITY

The nonstructural components throughout a 500,000 square foot manufacturing facility located in the heart of the New Madrid Seismic Zone were upgraded for improved seismic performance. The facility was originally built in the late 1970's with several periodic expansions constructed into the early 1990's. The project included anchorage and bracing of existing nonstructural components in both manufacturing and office space.

Following a structural evaluation confirming life safety structural performance, a facility-wide nonstructural earthquake risk assessment was conducted and concluded that many of the nonstructural components failed to satisfy the life safety performance objective defined in ASCE/SEI 41-06. A subsequent engineering design phase was performed to design bracing and

anchorage for nonstructural components not meeting the performance objective. The strengthening measures included bracing for all natural gas piping and equipment, fire protection piping systems, and emergency power systems as well as items whose damage could pose a threat to the life safety or the egress of building occupants. This included restraints for overhead office lights, bracing of tall unreinforced masonry walls and equipment suspended overhead, and anchorage of floor mounted equipment whose overturning or sliding could block the emergency exit routes for the facility.

The design began in 2006 with an 8 month construction schedule completed in mid-2008. The facility was fully operational throughout construction. Regular communication between the owner, design team, and contractor were cited as key to the project success. Scheduling requirements such as night shifts and work sequencing were incorporated into the design documents and the construction schedule to give the entire construction team a clear understanding of the challenges of working in a 24/7 manufacturing facility.

The approximate cost breakdown for the project in 2007 dollars is summarized in Table 4.5.1–1.

Table 4.5.1–1 Approximate Cost Breakdown for Manufacturing Facility Upgrade Project

	Project Cost
Consultant Fees (Design & Construction)	\$200,000
Construction Costs	\$700,000
Inspection and Testing	\$25,000
Total	\$925,000
Average Cost	\$2/square foot

4.5.2 EXAMPLE 2 – SCHOOL DISTRICT

A pilot project was undertaken to determine the magnitude of costs associated with implementation of nonstructural damage mitigation measures in a California school district. The pilot project addressed contents and equipment, overhead components and hazardous materials. Nonstructural hazards were surveyed and prioritized in three groups. The highest priority category included those items judged to pose the greatest safety risk. Among the components included were tall bookshelves and filing cabinets, suspended lighting, heavy

ceiling systems, and hazardous materials. Roughly half of the items at risk were judged to be in the highest priority category.

A total of seventeen schools were included in the pilot program. The current cost to address the highest priority items ranged from roughly \$20,000 per school (primarily to address tall cabinets and files) to \$400,000 per school in 2008 dollars (requiring work on suspended components as well as floor- and wall-mounted items).

4.5.3 EXAMPLE 3 – CALIFORNIA HOSPITAL

Seismic upgrading of nonstructural components was undertaken as a stand-alone project in response to SB 1953 regulations, which require California Hospitals to comply with specified nonstructural hazard reduction milestones by December 31, 2008 (see discussion in Section 4.1.1).

The subject hospital is a 228-bed acute care hospital of roughly 230,000 gross square feet, built in the 1970s. The project included anchoring and bracing nonstructural components in designated areas throughout the hospital including central and sterile supply, clinical laboratory service spaces, pharmacy, radiology, intensive care units, coronary care units, angiography laboratories, cardiac catheterization laboratories, delivery rooms, emergency rooms, operating rooms, and recovery rooms. Also included in the scope was the anchorage and bracing of mechanical and electrical equipment serving the designated areas.

Floor-mounted equipment, wall-mounted items weighing over 20 pounds, suspended equipment, piping, and ceilings were included among the items addressed in the project. Seismic anchorage was designed for compliance with 2001 California Building Code requirements.

The primary project challenge was to maintain uninterrupted hospital services 24/7 while accomplishing the mandated work. This required planning efforts by hospital administrators, doctors, nurses, the design team consisting of architects, structural, mechanical, and electrical engineers, contractors and subcontractors. Planning commenced in mid-2003; construction was completed at the end of 2007. The work was successfully completed by working in small areas at a time, often at nights for short durations. In order to complete the work in the intensive care unit, an available wing of the hospital was completely remodeled as “swing space” to enable patients to be relocated from the intensive care unit to the remodeled wing, thereby providing the contractor unrestricted access to complete nonstructural upgrading in the intensive care unit. Work throughout the hospital was complicated by the presence of asbestos

in the fireproofing at the underside of the floors. Hazardous material abatement preceded all work.

The cost breakdown for the project in 2007 dollars is summarized in Table 4.5.3–1.

Table 4.5.3–1 Cost Breakdown for California Hospital Upgrade Project

	Base Project	Swing Space	Total
Consultant fees	\$2,600,000	\$795,000	\$3,395,000
Construction	\$8,844,000	\$5,190,000	\$14,034,000
HAZMAT abatement	\$986,000	\$140,000	\$1,126,000
User equipment	\$0	\$760,000	\$760,000
Permits, inspection, testing	\$2,014,000	\$810,000	\$2,824,000
Total	\$14,444,000	\$7,695,000	\$22,139,000

Most of the project cost was attributable to the logistics of making improvements while maintaining uninterrupted hospital operations. The total construction cost of roughly \$100 per square foot demonstrates that the most cost effective nonstructural mitigation is undertaken when space is unoccupied such as during planned renovations.

5. NONSTRUCTURAL RISK REDUCTION FOR NEW BUILDINGS

Nonstructural risk reduction programs may vary depending on whether the nonstructural components in question are in an existing building, an historic facility, an essential facility, a facility containing hazardous materials, or are planned for a new building. The current chapter addresses issues related to new buildings; Chapter 4 addresses issues related to existing construction. Portions of these chapters are written in parallel, yet they are unique to each chapter. If portions apply to either situation, they appear only once. For instance, the material on implementation strategies appears only in Chapter 4; the material on current code requirements and code enforcement appears only in Chapter 5.

There is considerable overlap between the *new* and *existing* building categories. For instance, if an existing building undergoes a major alteration and changes to a higher use category, then it would be required to comply with current codes in many jurisdictions and thus, the project requirements would closely resemble those for new construction. Conversely, a new building becomes an existing building as soon as the occupancy permit is issued. Thus, tenant improvements and the installation of furniture, fixtures, equipment and contents for the first occupants of a leased portion of a new building often take place after the original design team is finished and the major architectural, mechanical, electrical, and plumbing components are installed; for this reason, many of the problems involved in coordinating the anchorage of the tenants' components with preexisting components are the same as for a project in an older existing building.

Historic buildings, essential buildings such as police and fire stations, or facilities that handle hazardous materials have special requirements, which are typically more complex than those for ordinary occupancies. While some issues related to these types of facilities are mentioned here, the treatment of nonstructural components in these facilities is beyond the scope of this guide. The list of references and additional sources of information may help address these issues for specialized facilities.

5.1 PROGRAM OBJECTIVES AND SCOPE

For new construction, it is possible to anchor, brace, or restrain all of the critical nonstructural items at the same time according to a chosen set of performance objectives and in conformance with current building code requirements. It is generally more efficient and less costly to install anchorage details during construction and at the time of initial occupancy than to upgrade them after the fact.

The planning stage for new construction is the ideal time to consider the desired seismic performance of a facility. It is an opportunity to coordinate the structural and nonstructural aspects of the design, for instance by selecting a structural system that provides a greater level of seismic safety and that will provide for a higher level of both structural and nonstructural performance. It is also critical to communicate concepts of seismic performance, risk, and related options to a building owner, in order to establish project specific design and construction strategies.

The following questions might help define the project objectives, including the nonstructural risk reduction objectives:

- What type of organization or business will occupy the facility?
- What type of functionality is needed during and after a minor, major, or severe earthquake?

Additional Questions for an Architect or Engineer to Consider

- What is the design life of the facility?
- What are the magnitudes and frequency of earthquakes the building is likely to experience during its life?
- Has a structural system been chosen that will provide the level of structural and nonstructural protection required? Is the structural system very stiff? Very flexible? Are the inter-story drifts large? Does the structural design include base isolation or energy dissipation devices such as structural dampers?
- What types of nonstructural components are proposed? Would damage to or failure of the proposed components be a life safety hazard or result in heavy property loss, or compromise building function? What is the cost of upgrading to more seismically resistant components and detailing?
- Does the design team have any control over future FF&E and contents? If not, who will have control? Can the design team coordinate the design and installation of these components with design representatives for the initial building occupants?

- How much structural and nonstructural damage can be tolerated after a minor, major, or severe earthquake?
- Do the design professionals have experience with bracing and anchorage of the types of nonstructural components proposed for the facility, particularly if the facility will need to be operational following an earthquake?
- For an important project, is there a third party peer reviewer for the seismic design, including the design for the nonstructural components?
- What is the value of proposed architectural finishes? MEP systems? Furniture, fixtures & equipment (FF&E) and contents? What would be the financial impact of damage to or failure of each of these items?
- How much of the potential earthquake losses will be covered by insurance?

It is worth repeating that the nonstructural components and contents typically represent the major portion of the capital investment for new construction; per Figure 2.1.3–1, this is 82% for office buildings, 87% for hotels, and 92% for hospitals (Whittaker and Soong, 2003).

Incorporating seismic damage control measures into the design for new construction makes good business sense, particularly for buildings that have a high probability of experiencing damaging earthquakes several times during their life span. For new construction of essential buildings in high seismic areas, damage control measures are now required, in order to increase the likelihood that these facilities will remain functional following a major earthquake.

5.1.1 VOLUNTARY VS MANDATORY RISK REDUCTION

Although code provisions historically have been written with the primary intent to provide a minimum level of life safety and to avoid legislating property damage control measures, code provisions now mandate an increasing level of damage control for certain types of essential and high occupancy facilities. Facilities where higher standards are currently mandated include hospitals, aviation control towers, designated emergency shelters, police and fire stations, power generating stations, water storage or pumping facilities, facilities that handle hazardous materials, and a number of others (Occupancy Category IV in ASCE/SEI 7–10 *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2009)). Except in areas with the lowest seismicity, the structural and nonstructural design of these facilities must now meet more stringent design requirements than for standard construction.

For standard construction, a “code design” is intended to provide a minimum level of life safety, now considering both structural and nonstructural components, but it does not provide for significant damage control. In order to achieve enhanced performance (e.g., *Operational*,

Immediate Occupancy, or a higher level of structural and nonstructural damage control), the design objectives must be targeted higher than the life safety level implicit in the minimum code provisions. Although new construction must meet the minimum life safety standards, owners concerned with building functionality or future earthquake losses may choose to implement a higher standard and to incorporate damage control measures into the design for new construction on a voluntary basis.

5.1.2 PERFORMANCE-BASED DESIGN CONCEPTS

The use of performance-based design concepts requires a discussion between building design professionals and their clients about performance expectations and seismic risk tolerance. Performance-based design provides terminology to characterize seismic risk and seismic performance and provides a framework for making comparisons between varying levels of seismic hazard, structural and nonstructural performance, postearthquake functionality, acceptable and unacceptable damage, and total earthquake losses over the expected life of the facility. Design professionals, organizational risk managers, building owners, business owners, and tenants all need to develop an understanding of the tradeoffs between risk and reward; that is, an understanding that seismic design and investment choices have a relationship to expected future performance and potential future losses. The parties all need to understand that they make choices, both passive and active, based on their understanding of the issues and their seismic risk tolerance. One may

Voluntary Adoption of Enhanced Performance Criteria

At their discretion, owners may adopt more stringent seismic design standards than those in the prevailing code.

- Beginning in the late 1970s, some owners of high tech research and manufacturing facilities in California started to use higher standards for the seismic design of critical buildings and nonstructural components on a voluntary basis.
- In the mid-2000s, several thermoelectric power plants in Chile were designed using a special seismic performance criteria stipulated by the owners that require that any damage to the plants from a major earthquake be limited to that which could be inspected and repaired within 14 days time; further, the criteria require that these plants remain operational during moderate seismic events.

In these examples, the owners developed special seismic design criteria to meet the needs of their organizations, primarily motivated by a desire to limit costly postearthquake outages.

choose to live with known seismic risks or choose to initiate programs to reduce some or all of the known hazards; either way, a choice must be made.

Performance-based design concepts have been in development for several decades; this development is ongoing. These concepts are gradually finding their way into the building codes used for new construction, such as IBC 2009 *International Building Code* (ICC, 2009) and ASCE/SEI 7-10). These codes now specify higher seismic design forces and more comprehensive requirements for nonstructural components in certain types of facilities in an effort to reduce the earthquake damage and improve the performance of these facilities. Nevertheless, the code does not address damage control or postearthquake operations for standard occupancies. If an owner wants to specify higher performance standards than those embodied in the code, it is important that those performance expectations be identified early in the planning process.

Borrowing some terminology used in ASCE/SEI 41-06 *Seismic Rehabilitation of Existing Buildings* (ASCE, 2006) for the rehabilitation of existing construction and previously described in Chapter 4, target building performance levels may be described as *basic* or *enhanced*. Limited performance objectives, those that provide less than the minimum life safety standard, while permissible for existing construction, are not allowed for new construction.

- A *basic* level of safety is achieved by following the code requirements for standard occupancies. This type of design should not be expected to provide significant damage control for structural or nonstructural components or to provide for continued operations or immediate occupancy after an earthquake.
- An *enhanced* performance level is achieved by following both structural and nonstructural code requirements for essential facilities. Enhanced performance could be achieved for nonessential facilities by using some or all of these additional requirements.
- Enhanced performance might also be provided by developing project-specific seismic design criteria to meet the needs of a particular organization (see sidebar on previous page). These criteria should be developed and implemented by design professionals with specific experience with performance-based design. Engineering analysis methods, such as those using nonlinear or push-over techniques, are available that can be used to check whether or not the design meets the target performance objectives.

It is important that the design objectives be clear from the outset, so that the owner and design professionals are in agreement on what they are trying to achieve. Design and construction contracts must all include language describing the responsibilities of the designers,

contractors, subcontractors, specialty subcontractors, vendors, and inspectors to provide systems and details that will meet the project objectives; this is particularly important if these are enhanced performance objectives that are higher than for a “code design.” Budgets and schedules will all have to take into account the resources and time required to achieve the project goals.

5.2 DESIGN CONSIDERATIONS

The selection of design solutions must be consistent with the scope and objectives selected for the project. For all items covered by the code provisions, design solutions must comply with the applicable building codes and standards, such as ASCE/SEI 7–10. For the engineering consultants engaged to provide design solutions, the selection of seismic force levels, design coefficients, and design methods depends upon the Seismic Design Category. The design team and owner need to be clear about the performance objectives and the level of seismic protection that will be targeted. There may be items that are not explicitly covered by the code, for which some design solutions can be implemented by the owner or the initial tenants without consideration of the building code and without engineering expertise.

Specific design solutions for nonstructural items fall into three broad categories. These were described in Chapter 4 and are repeated here because the application is somewhat different for new construction.

NON-ENGINEERED (NE): These are typically simple, generic details or common sense measures that can be implemented by a skilled laborer or by maintenance personnel using standard items from a hardware store. Although these solutions are not appropriate for essential facilities, they may be useful for the restraint of items not directly covered by code provisions, such as furniture and contents that lie below the code threshold but that may still fall and injure occupants. Some of these solutions might be implemented by the owner and the original design team; others by the initial tenants.

PRESCRIPTIVE (PR): Prescriptive details are available in the public domain and have been engineered to meet or exceed code requirements for a set of common conditions; they can be used directly in many situations. While there are only a limited number of these details currently available, we anticipate that more such details will be developed as engineers, architects, and specialty contractors become more familiar with the new ASCE/SEI 7–10 requirements for nonstructural components. Some of the prescriptive details have been developed for hospitals, schools and residences in California, and

have been successfully implemented for many years. Examples are provided in Chapter 6.

ENGINEERING REQUIRED (ER): These are nonstructural anchorage details specifically developed by a design professional on a case-by-case basis for a specific set of conditions. Design methods and design coefficients are selected based on the Importance Factor and Seismic Design Category, per IBC 2009 and ASCE/SEI 7-10, as discussed in Section 5.3.1 below. Higher design forces and more complex engineering methods may be required to meet performance objectives higher than those embodied in the building code provisions.

5.3 BUILDING CODE REQUIREMENTS

5.3.1 2009 EDITION OF THE INTERNATIONAL BUILDING CODE (IBC 2009)

The current code requirements for nonstructural components are contained in ASCE/SEI 7-10 Section 13 which is adopted by reference in IBC 2012 *International Building Code* (ICC, 2012). In recent years, engineers, researchers, and code committees have paid increasing attention to the issues of nonstructural performance. As a result, ASCE/SEI 7-10 now includes a 15-page chapter devoted to nonstructural components and contains design requirements for both force- and displacement-controlled nonstructural components. In contrast, the 1994 UBC *Uniform Building Code* (ICBO, 1994) covered the nonstructural requirements in less than two pages, where the focus of the requirements was primarily on position retention of the components. The requirements are now more detailed and include explicit provisions for more items that apply to facilities that require postearthquake functionality.

The most stringent design provisions are driven by the Component Importance Factor, I_p . Any component with an I_p of 1.5 is considered a “Designated Seismic System” for which special provisions apply. This includes systems required to function for life safety purposes after an earthquake including sprinkler systems and egress stairways; components used to convey, support or contain toxic, highly toxic, or explosive substances or hazardous materials; or components needed for continued operation of essential facilities.

Additional distinctions in the design provisions are based on the Seismic Design Category, which ranges from A through F and depends on the Occupancy Category (I, II, III, or IV) and the ground motion parameters (S_{DS} and S_{D1}) generally as follows:

- Seismic Design Category A: All Occupancy Categories in areas with minimal seismicity; these facilities are exempt from the nonstructural requirements.
- Seismic Design Category B: Occupancy Categories I, II, and III in areas with low seismicity
- Seismic Design Category C: Occupancy Categories IV in areas with low seismicity and Occupancy Categories I, II and III in areas with moderate seismicity
- Seismic Design Category D: Occupancy Categories IV in areas with moderate seismicity and All Occupancy Categories in areas with high seismicity
- Seismic Design Category E: Occupancy Category I, II or III in areas of very high seismicity and near an active fault
- Seismic Design Category F: Occupancy Category IV in areas of very high seismicity and near an active fault
- Seismic Design Category F (essential facility in area with very high seismicity) has the most stringent nonstructural requirements;

The seismic design forces are based on a variety of factors including the weight of the item, the ground acceleration and soil type, the flexibility of the component and its attachments, the location in the building, and an importance factor. In general, design forces are higher for flexible components and flexible attachments; higher for items anchored higher in the building; higher for items that contain hazardous

Seismic Design Forces for Nonstructural Components (ASCE/SEI 7-10)

The seismic forces used to design supports and anchorage for nonstructural items are based on a percentage of the weight of the item and the following additional factors:

- S_{DS} A factor for the seismic acceleration at the ground level, based on soil type and seismic zone
- a_p A component amplification factor that varies from 1.0 (for rigid components and attachments) to 2.5 (for flexible components and attachments)
- $(1+2(z/h))$ An amplification factor based on the ratio of the height of the point of attachment in the building (z) to the overall height (h); it ranges from 1 at the base to 3 at the roof
- I_p A component importance factor equal to 1.0 for typical components, or 1.5 for some components required for life safety, essential operations, or that contain hazardous materials
- R_p A component modification factor that varies from 1 to 12 and has the effect of reducing the design forces for more deformable or ductile components (highest values assigned to piping with welded joints; lowest to brittle elements such as URM partitions)
- W_p operating weight of the component

materials, that are needed for life safety functions, or that are needed for continued operations of an essential facility; and lower for items with high deformability or high ductility.

Minimum and maximum limits on design forces are specified in the code. For a given acceleration and importance factor, the range from minimum design forces ($0.3S_{DS}I_pW_p$) to maximum design forces ($1.6S_{DS}I_pW_p$) is a factor slightly greater than 5. Thus, a flexible item anchored at the roof of a building might be designed for up to 5 times more force than a rigid item anchored at the base of the same building.

For items affected by differential movement and building distortion, the code requires that the design consider the relative lateral displacements both within and between structures. This would affect the design of such components as pipe risers and precast panels, which are connected to adjacent floors, and piping, cable trays, ductwork, or architectural finishes crossing seismic joints.

The code includes provisions for architectural, mechanical, and electrical components, supports, and attachments. Tables of design coefficients a_p and R_p are provided for dozens of architectural, mechanical, and electrical components. Where design of nonstructural components or their supports and attachments is required by code, such design must be shown in construction documents prepared by a registered design professional. It is not sufficient to provide a note saying "All ceilings to be braced"; the bracing details must be included on the plans and covered in the project specifications.

Exemptions for Nonstructural Components

The following items are specifically exempt from the ASCE/SEI 7-10 seismic design requirements for nonstructural components:

1. Most furniture and temporary or movable equipment.
2. Most components in Seismic Design Categories B and C (i.e., normal occupancies in areas of moderate seismicity).
3. Mechanical and electrical components in Seismic Design Categories D, E and F, where all of the following apply:
 - a. I_p is equal to 1;
 - b. The component is positively attached to the structure;
 - c. Flexible connections are provided between the components and associated ductwork, piping and conduit are provided, and either
 - i. The component weighs 400 lb or less and has a center of mass located 4 feet or less above the adjacent floor level; or
 - ii. the components weighs 20 pounds or less or, in the case of a distributed systems, weigh 5 pounds per foot or less.

Earlier provisions related to nonstructural components in the 2000 and 2003 IBC were concerned primarily with position retention, i.e., preventing components from becoming dislodged or overturned during an earthquake. ASCE/SEI 7-10 contains additional provisions related to postearthquake functionality that are applicable to components with hazardous contents and to equipment that is required to remain operational following an earthquake. For such designated seismic systems, where I_p is 1.5, certification based on approved shake table testing or experience data must be submitted to the authority having jurisdiction.

The code contains a number of significant exemptions (see sidebar above) and does not contain requirements for many components, such as furniture (except permanent floor-supported storage cabinets, shelving or book stacks over 6 ft tall), and movable fixtures, equipment and contents that are supplied by tenants and building occupants. For areas with moderate or high seismicity, the risks associated with many of these components can be reduced by following the suggestions contained in Chapter 6.

Alternative Methods

The code formulas used to compute the design forces on nonstructural components in buildings contain a number of simplifying assumptions regarding damping, response amplification, possible resonance between the equipment and the structure, and the distribution of forces over the height of the structure. For some facilities, more sophisticated analyses may be warranted. The Tri-Service Manual “Seismic Design Guidelines for Essential Buildings” (TM 5-810-10-1) describes an approximate floor response spectrum method that considers two earthquake levels and takes the multi-mode response of the building into account. Beyond that, an analytical model of the building can be used to generate floor response spectra at critical equipment locations, and these spectra can be used to determine the design forces for the nonstructural components and equipment.

5.3.2 ENFORCEMENT OF CODE REQUIREMENTS

The effectiveness of model code requirements governing seismic design of nonstructural components depends on technically sound code provisions, proper application by designers, and code enforcement. Proper enforcement requires both comprehensive plan review and thorough construction inspection.

PLAN REVIEW

A comprehensive plan review includes determination of which items require seismic design; and an examination of the details for compliance with code requirements. Determining which items require seismic bracing involves a review of the construction drawings and specifications for each discipline (e.g., architectural, electrical, mechanical, plumbing, and other specialties). Few jurisdictions, if any, have resources devoted to such a comprehensive review of construction documents, and few jurisdictions have reviewers qualified to comprehensively evaluate compliance with all nonstructural code requirements.

An additional challenge in plan review arises from the many items that are commonly excluded from construction drawings, but are identified in the project specifications to be procured from the contractor on a “design–build” basis. Unless these items are carefully tracked and submitted for review, building department plan review can be nonexistent. Few jurisdictions have mechanisms in place to track and support ongoing review of nonstructural seismic bracing designs developed during construction. The responsibility matrices included in Appendix B are intended to aid project managers in the assignment and tracking of responsibility for nonstructural seismic protection. Used in conjunction with the specification section provided in Appendix A, the responsibility matrices can be used to facilitate compliance with nonstructural performance objectives.

CONSTRUCTION INSPECTION

Enforcement of nonstructural seismic requirements is often lacking in the construction inspection process. Since details associated with seismic restraint of nonstructural components are not often fully shown on approved drawings, inspectors are left without the tools necessary to evaluate the adequacy of as–built installations. Historically, building inspectors have not been systematically trained to inspect the seismic restraint of nonstructural components, and few inspectors have sufficient experience to field review seismic restraints of nonstructural components that are not covered by a well known standard.

Many design professionals have the necessary training and experience to evaluate the adequacy of nonstructural seismic restraints; however, field observation of nonstructural component installations is often not included in their scope of work. As a result, it is not uncommon for nonstructural components to be installed without inspection.

IBC 2009 contains requirements for special inspection of designated seismic systems. For most buildings, a written statement of special inspection must be prepared by a registered design

professional. In buildings assigned to Seismic Design Categories C, D, E or F, the statement of special inspection must include seismic requirements for selected HVAC components, piping systems and electrical equipment. These code requirements are expected to increase the construction oversight of nonstructural installations and ultimately, to improve the seismic performance of nonstructural components.

5.3.3 REQUIREMENTS FOR CONTENTS

Building contents, such as furniture, kitchen and laundry equipment, movable partitions, and storage shelving are typically considered separate from the building and are usually the responsibility of the building occupant, not the owner or the original design team. Many such items are specifically exempted from seismic provisions in model building codes (e.g., furniture, floor-mounted equipment weighing less than 400 pounds, and suspended items weighing less than 20 pounds). Regulated by the code or not, contents can pose an additional risk to safety and continuity of operations after an earthquake. The seismic protection of contents is dependent upon an understanding of potential seismic risk, followed by action to mitigate that risk on the part of business owners, homeowners, and tenants. The content examples included in Chapter 6 provide guidance for the bracing and anchorage of many common furniture and content items and can be adapted for other similar items. Building code provisions, guidance documents, or other resources listed in the references can be effectively applied to the design and installation of seismic protection measures for building contents.

5.3.4 OTHER STANDARDS AND PROTOCOLS

Many of the challenges related to design, plan review, and construction inspection are resolved when installation in accordance with nationally accepted standards becomes a construction standard of practice. For example, 2009 IBC accepts seismic restraint of fire protection systems designed in accordance with the National Fire Protection Association's NFPA 13 *Standard for the Installation of Sprinkler Systems* (2007). As a result, verification of NPFA 13 compliance is a common occurrence in the field. Similar examples exist for other major nonstructural components: Installation of suspended ceilings in accordance with ASTM C635, ASTM C636, and the *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM E580/E 580M-09a) is included in the IBC by reference.; Selected additional industry standards are listed in Appendix B of the ATC-69 *State-of-the-Art and Practice Report* (ATC, 2008).

Qualification testing is an acceptable alternative to the analytical requirements of the code. IBC 2009 accepts seismic qualification based on nationally recognized testing procedures, such as the, ICC-ES AC 156 *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems* by the International Code Council Evaluation Service. Standard 171-2008 *Method of Test of Seismic Restraint Devices for HVAC&R Equipment* (ANSI/ASHRAE, 2008) provides additional test methods used in the HVAC industry. Selected additional testing protocols, such as FEMA 461 report, *Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components*, are listed in Appendix B of the ATC-69 *State-of-the-Art and Practice Report* and repeated here in Appendix F.

5.3.5 VALIDATION AND REFINEMENT OF CODE REQUIREMENTS

Seismic design requirements for structural systems have evolved over time as a result of documented earthquake performance and laboratory testing. Seismic design requirements for nonstructural components have also evolved over time; however, comprehensive evaluation of these requirements, either by testing or through postearthquake observations, has been limited. Future earthquakes might be able to provide the information necessary to validate or refine current design requirements, but comprehensive and systematic postearthquake documentation of nonstructural performance is needed. Obstacles to gathering such perishable data will need to be overcome before a quantitative review of nonstructural seismic design requirements can become possible.

5.4 RESPONSIBILITY AND PROJECT MANAGEMENT

Who is responsible for ensuring that nonstructural components are protected from earthquake damage and that design solutions are consistent with the chosen performance objectives? Who is responsible for the design of which types of components? Who provides oversight for the design of the many, potentially interconnected nonstructural items? Who resolves conflicts in cases where different design solutions in different disciplines are incompatible? Who provides oversight for the installation, and inspection for all of the nonstructural items?

Architects, mechanical, electrical and civil or structural engineers, interior designers, landscape architects, construction managers, contractors, specialty subcontractors, equipment manufacturers, vendors, inspectors, testing agencies, plan reviewers, developers, owners, tenants – all these parties may be involved. Coordination of this effort is not a trivial task; the issue of nonstructural seismic risk reduction must be part of the initial planning, so that

decisions regarding the structural system, the architectural finishes, the MEP systems, the landscaping immediately adjacent to the building, and the equipment purchases are all made in accordance with a unified plan that is consistent with the performance goals and the project objectives. It may be advisable to assign a dedicated design professional to the oversight of the design and installation of the nonstructural items.

Questions such as the following must be addressed from the beginning:

- Would a base isolated building provide the best protection for the costly equipment in this facility and allow for continued operations?
- Would a stiff structural system or a flexible structural system be more compatible with the performance objectives for the nonstructural items? Can this structural system be adapted for the architectural design? Can the architectural design be adapted to a more appropriate structural design?
- If the structural system is flexible, will the architect specify flexible finishes and avoid the use of adhered veneers, marble panels, stucco soffits or other items likely to be damaged by inter-story drift?
- If the architect specifies exterior adhered veneer, can the landscape architect provide a wide planting strip around the building perimeter to protect against falling hazards? Will the architect be willing to specify

Potential Issues for Specialized Facilities

The following are additional considerations for highly specialized or essential facilities:

- For facilities that depend on unique or specialized equipment that would take a long lead time to replace, is there a way to incorporate a secondary or backup system into the design that would reduce potential outages if the equipment were damaged? Would higher design forces or base-isolation reduce the equipment damage? Is there a need to provide budget and space to stock spare parts or spare equipment?
- For facilities that must remain operational following an earthquake, does the design incorporate elements that would be needed in the event of a catastrophe with lengthy infrastructure outages? The hospital that fared the best following Hurricane Katrina in New Orleans had the following elements in place prior to the hurricane: reserve tanks with water to flush toilets, diesel fuel to run the emergency generators, and gasoline for company vehicles.
- The following questions should also be considered: Would space be needed to provide temporary accommodations for employees? Would a forklift, a backhoe, or other construction supplies and equipment for emergency repairs, backup communications equipment such as ham radios, emergency food supplies, and a designated place for sanitary and waste disposal be needed?

something other than the adhered veneer above exits?

- For facilities that need to provide certification for specified MEP equipment, is certified equipment already available that is appropriate for the facility, or will money need to be budgeted for detailed analysis or shake table testing?
- At what point in the design process will information be available from the structural engineer regarding the behavior of the structural frame, such as inter-story drifts and other information required for the nonstructural design?
- Since lateral forces are higher on the roof, what MEP items are required to be located at the roof level and what items can be relocated lower in the building?
- Are there architectural finishes available that would facilitate the inspection of earthquake damage? Can hatches, openings, or removable panels be provided that would make it easier to inspect structural framing, precast panel connections, piping, or ducts after an earthquake and thus, get occupants back into the building sooner?

5.4.1 EXAMPLE: RESPONSIBILITY MATRIX

New construction projects typically involve the coordination of numerous parties with overlapping responsibilities and competing or conflicting interests; adding a comprehensive program to brace and anchor nonstructural components and contents makes a new construction project even more complex. Assigning clear responsibility for each nonstructural component and tracking the design, peer review, plan review, installation, observation, and special inspection is very important.

Figure 4.4.1–1 shows an example of a responsibility matrix that could be readily adapted by listing the nonstructural components for a particular project. This sample format can be used to track who is responsible for design, design review, installation, and observation. If peer review or special inspection is required, these could be added to the table. More comprehensive responsibility matrices, developed for each Seismic Design Category and compliance with ASCE/SEI 7–10, are provided in Appendix B. These matrices are intended to serve as templates for use by project managers in assigning and tracking design, construction and inspection responsibilities. They can be used in conjunction with the specification provided in Appendix A and are intended to serve as a roadmap for implementation. Successful use of these tools starts with development of a comprehensive project-specific list of nonstructural components to be addressed.

5.4.2 EXAMPLE: SEISMIC CODE BLOCK, SAINT LOUIS COUNTY, MISSOURI

When the 2003 International Building Code (ICC, 2003) was adopted in Saint Louis County, Missouri, enforcement of the seismic requirements for nonstructural components was complicated by varying interpretations by design professionals, code compliance plan reviewers, contractors and building inspectors. In response, the County established rules and regulations intended to provide a common set of standards for compliance with the Building Code. A cornerstone of the rules and regulations that were adopted is the requirement for a "Seismic Code Block" on the mechanical, electrical, and plumbing drawings (Figures 5.4.2-1 and 5.4.2-2). The seismic code block requires that the engineer(s) responsible for the design of the mechanical, electrical, and plumbing systems identify the location of the details for anchorage and sway bracing of equipment and system components on the plans, or indicate that they will be furnished by subsequent submission, which will be reviewed by the engineer responsible for the design. Saint Louis County requires accountability for the design and documentation of nonstructural bracing requirements. Installation and building inspection is facilitated by the availability of project-specific bracing details. Use of the Seismic Code Block on all projects could significantly enhance the enforcement of code requirements for seismic bracing of nonstructural components and systems. The Saint Louis County model is expected to serve as a model for other jurisdictions throughout the country.

12/1/05 Attachment "A" of St. Louis County Rules & Regulations
Anchorage & Sway Bracing Mechanical & Electrical System Components
 SEISMIC CODE BLOCK ON 1ST SHEET OF MECHANICAL & PLUMBING PLANS
 MECHANICAL & PLUMBING EQUIPMENT COMPONENTS
 EARTHQUAKE LOAD RESISTANCE

Seismic Use Group ()		Seismic Design Category ()						
LISTING OF EQUIPMENT AND SYSTEM COMPONENTS	ANCHORAGE TO FLOORS, ROOFS, ETC.		SWAY BRACING		LOCATION OF PROFESSIONALLY SEALED ANCHORAGE AND SWAY BRACING DETAILS			COMMENTS
	Not Provided	Provided	Not Provided	Provided	ON CONST. DOCUMENTS	SUBSEQUENT SUBMITTAL		
					<u>Drawing No. or Spec. Section</u>	Shop Drawings	Separate Permit & Plans	
FIRE PROTECTION, DETECTION & ALARM EQUIPMENT & SYSTEM COMPONENTS; * See Attachment "C" Table 200 (List items such as; fire sprinkler system equipment & system components, smoke control & evacuation equipment & system components)								
HAZARDOUS EQUIPMENT & SYSTEM COMPONENTS; * See Attachment "C" Table 200 (List items such as; gas piping, piping containing flammable, combustible liquids & gasses or toxic chemicals. Include items such as flammable & combustible tanks, vats & other industrial equipment containing hazardous or toxic liquids, gasses, chemicals, etc.)								
OTHER EQUIPMENT & SYSTEM COMPONENTS NEEDED FOR CONTINUED OPERATION OF SEISMIC USE GROUP III FACILITIES OR WHOSE FAILURE COULD IMPAIR THEIR CONTINUED OPERATION. * See Attachment "C" Table 200 (List items)								
OTHER GENERAL EQUIPMENT & SYSTEM COMPONENTS (List items such as; boilers, furnaces/AHU's, tanks, heat exchangers and pressure vessels, suspended piping, water heaters, VAV boxes, HVAC ducts, drain waste & vent piping, pumps, etc.)								

Figure 5.4.2-1 Seismic Code Block worksheet.

12/1/05 Attachment "B" of St. Louis County Rules & Regulations
Anchorage & Sway Bracing Mechanical & Electrical System Components

SEISMIC CODE BLOCK ON 1ST SHEET OF ELECTRICAL PLANS

ELECTRICAL SYSTEM COMPONENTS
EARTHQUAKE LOAD RESISTANCE

Seismic Use Group ()	LISTING OF EQUIPMENT AND SYSTEM COMPONENTS	ANCHORAGE TO FLOORS, ROOFS, ETC.		SWAY BRACING		LOCATION OF PROFESSIONALLY SEALED ANCHORAGE AND SWAY BRACING DETAILS			Seismic Design Category ()	COMMENTS
		Not Provided	Provided	Not Provided	Provided	ON CONST. DOCUMENTS <i>Drawing No. or Spec. Section</i>	SUBSEQUENT SUBMITTAL			
							Shop Drawings	Separate Permit & Plans		
	FIRE PROTECTION, DETECTION & ALARM EQUIPMENT, & SYSTEM COMPONENTS; * See Attachment "C" Table 200 (List items such as fire alarm panels, electric conductors powering fire protection equipment, etc.)									
	EMERGENCY OR STANDBY EQUIP. AND SYSTEM COMPONENTS; * See Attachment "C" Table 200 (List items such as emergency generators, panel boards, single hanger and trapeze supported system components, bus-ducts, primary cable systems, motors control centers and devices, switch-gears, transformers, unit substations, cable tray, conduit, lighting fixtures, etc.)									
	OTHER EQUIPMENT & SYSTEM COMPONENTS NEEDED FOR CONTINUED OPERATION OF SEISMIC USE GROUP III FACILITIES OR WHOSE FAILURE COULD IMPAIR THEIR CONTINUED OPERATION * See Attachment "C" Table 200 (List items)									
	OTHER GENERAL EQUIPMENT & SYSTEM COMPONENTS (List items such as panel boards, single hanger & trapeze supported system components, communication systems, electrical bus ducts, primary cable systems, electrical motor control centers, motor control devices, switchgear, transformers, unit substations, cable tray, conduit, lighting fixtures, etc.)									

Figure 5.4.2-2 Seismic Code Block worksheet.

The code block above, adopted in 2006, only addresses MEP components that are explicitly covered on the construction documents. Nevertheless, it provides a model for keeping track of these items. The project architect or design professional responsible for the general oversight of the nonstructural protective measures could expand this table to cover the various architectural, FF&E, and content items that are within the control of the original design team and use this as a tool for tracking the design and plan review for these items. Revised May 2010, the St. Louis County Rules and Regulations include requirements for architectural and MEP components and provide a standardized form to be used to track construction inspections (see <http://www.co.st-louis.mo.us/pubworks/documents/NTIseismicRegs.pdf>). This document includes examples of forms filled out as intended, with each equipment item provided a separate line item in the code block. As with any tool, the seismic code block is only effective if the design team provides a complete list of the relevant items covered by the code provisions.

6. SEISMIC PROTECTION OF NONSTRUCTURAL COMPONENTS

6.1 PROTECTIVE MEASURES

Reducing nonstructural hazards requires a combination of common sense measures and additional protective measures that involve the installation of seismic anchorage and bracing. The protective measures recommended in this Chapter will go a long way toward reducing the earthquake hazards from nonstructural components.

6.1.1 COMMON SENSE MEASURES

A facility survey may identify components that represent a high or moderate risk in their present location but that could readily be relocated or rearranged, in order to reduce the potential risk. The answers to the following questions may help identify common sense measures available to reduce many of these risks:

- Which areas of the building have a higher occupant load and hence a potentially higher life safety risk?
- Are there heavy, unstable items currently located near a desk or bed, which could be moved?
- Are the exits and exit pathways clear, or are there items that could block doors, corridors, or stairways if they were to fall?
- What is the probability that someone will be injured by falling objects?
- Can items no longer serving a useful function be removed?
- Are all hazardous materials stored properly?
- Which items can be relocated to prevent possible injury and do not need to be anchored, in order to prevent damage or loss?
- If something slides or falls, in what direction is it likely to move?
- Is a suspended item currently hanging where it may impact a window, wall, or another item?

While the answer to these questions may not always be obvious, some simple steps may go a long way toward reducing the related nonstructural risks. The primary investment here is the time required to relocate furniture, reshel items, or rearrange hazardous chemicals. For instance:

- Tall or heavy objects can be relocated, so that they cannot block an exit or fall onto a desk or bed.
- Shelved items might be rearranged so that heavier items are near the bottom and lighter ones are near the top.
- Falling hazards, such as curios, potted plants, and flower vases can be relocated, so that they will not fall on a bed or desk.
- Hanging objects can be relocated to a place where they will not impact one another or a window.
- Incompatible chemicals can be separated, in order to prevent mixing if the containers should break.
- Excess supplies or inventory can be stored in their original shipping containers until ready for use, in order to reduce the possibility of breakage.
- Rarely used files or materials can be moved to an offsite storage facility or be disposed of.
- Important electronic files should all be backed up to an offsite facility in a different geographic area, which would not be affected by the same earthquake.

6.1.2 NONSTRUCTURAL COMPONENT PROTECTION MEASURES

There are many techniques available to reduce potential nonstructural earthquake damage. Possible upgrade schemes might include one or more of the following seismic protection measures:

- Using anchor bolts to provide rigid anchorage to a structural floor or wall
- Bracing the item to a structural floor or wall
- Providing a tether or safety cable to limit the range of movement if the item falls or swings
- Installing bracing or anchors for architectural appendages such as chimneys, parapets, canopies, marquees, or signs; anchoring masonry veneer and cornices

- Providing stops, bumpers or snubbers to limit the range of movement if the item is on vibration isolators or can slide or swing
- Providing flexible connections for piping and conduit where they cross seismic joints or connect to rigidly mounted equipment
- Attaching contents to a shelf, desktop, or countertop
- Providing base isolation or seismic shock absorbers for individual pieces of vital equipment

Some of these methods are designed to protect the functional integrity of a particular item; some are designed merely to reduce the consequences of failure. It is important to understand the applicability and limitations of the various upgrade schemes and to select an appropriate scheme for a particular item in a specific context. It is also important to select upgrade details that are consistent with the program objectives: measures required for immediate occupancy or continued operations are typically more complex than those required solely to reduce falling hazards. Measures used to restrain new items may differ from those used to restrain existing items, particularly if the restraint for the existing items is intended to meet only limited objectives and to reduce falling hazards. Critical and expensive items, library and museum collections, hospitals, essential facilities, laboratories, and industrial clean rooms may all require special attention.

Requirements for Postearthquake Operations

Facilities to be upgraded to *Immediate Occupancy* or *Operational* performance level during a major earthquake may require extensive modifications and implementation of an ongoing risk reduction program. In order to achieve these enhanced objectives, any or all of the following elements may be needed in order to provide an appropriate level of nonstructural protection:

- Specialized engineering expertise from design professionals experienced with nonstructural seismic protection
- Higher design forces than those required by code for the basic safety objective
- Experienced specialty contractors
- Special construction inspection
- Load-rated hardware and specialty seismic restraint items
- Equipment that is certified by the vendor to remain operational either by analysis, shake table testing, or experience data
- Components with hazardous contents that are certified to maintain containment either by analysis, shake table testing, or experience data
- Equipment or piping with special design details such as dampers or base isolation

Some structural upgrades may also be required in order to meet the operational objectives such as larger seismic gaps to prevent pounding between adjacent structures, or stiffer structural systems such as shear walls to avoid excessive distortion of the structural framing. Structural measures to reduce seismic hazards are addressed in ASCE 31–03 and ASCE 41–06 but are beyond the scope this document.

6.2 NONSTRUCTURAL COMPONENT EXAMPLES

The tables in this chapter and the checklists and risk ratings in the appendices all have similar numbering; illustrated examples are provided for many, but not all, of the components listed. The components addressed herein have been grouped under three major headings:

- Architectural Components
- Mechanical, Electrical & Plumbing (MEP) Components
- Furniture, Fixtures & Equipment (FF&E) and Contents

Each of these three major categories includes a number of subcategories. The checklists and risk ratings in Appendices D and E address all of the subcategories; examples are also provided here for each of the components listed. This document has been prepared as a web-based document with the idea that additional examples may be added in the future.

The nonstructural component examples typically consist of the following elements:

- **Typical Causes of Damage:** A brief description relevant to the particular item.
 - **Damage Examples:** The photographs presented here cover a variety of situations and have been taken over a 39-year period. Photographs from the 1971 San Fernando Earthquake generally show damage to components that were not restrained, while some of the more recent photographs depict damage to components that appeared to be braced or anchored but whose bracing and anchoring details were apparently inadequate to resist the severity of the shaking. Photos from the 2010 Haiti, Chile, Eureka, California, Baja California, and Christchurch, New Zealand Earthquakes have been included, illustrating the ongoing problems with nonstructural performance.
- **Seismic Mitigation Considerations:** A description of issues relevant to the mitigation of the particular item.
 - **Mitigation Examples:** The photographs presented here show braced and anchored components. Most are examples of properly anchored components; some show improper installations with an explanation of the problem(s).

- **Mitigation Details:** Usually one or more suggested details that can be used to reduce the seismic vulnerability of the item. These details are not engineering drawings; in general, they have been drawn with shading to represent the appearance of the properly anchored item. The protection measures or seismic anchorage details are classified as Non-Engineered (NE), Prescriptive (PR), or Engineering Required (ER); these terms are described below.

6.2.1 TYPICAL MITIGATION DETAILS

NON-ENGINEERED (NE) DETAILS

These are simple, generic seismic protection details that do not require engineering design to determine the requirements. Some examples of types of nonstructural protection that can be designed and implemented without an engineer include:

- Restraints for tenant-supplied movable equipment and furniture
- Restraints for cabinet doors and drawers
- Restraints for shelved items

For these types of elements, generic restraint details are usually sufficient to provide adequate protection. The earthquake forces on these elements are generally small compared to the strength of the restraint methods that are usually recommended. Together with the installation guidelines at the end of this chapter, enough information is provided to enable someone without specialized expertise in the field to install the restraint shown using common tools and readily available materials. Many vendors now sell off-the-shelf seismic restraints that can be used for these Non-Engineered details; check the internet for available hardware.

There are limitations to the use of non-engineered seismic protection measures: this method should only be used for elements that are relatively lightweight. Non-engineered restraints should not be used for elements that are considered critical, such as emergency power systems, large inventories of hazardous materials, or in hospitals, where immediate postearthquake operations are desired.

PRESCRIPTIVE (PR) DETAILS

These mitigation solutions rely on standard restraint details that have been previously developed and can be implemented without the need for an engineer. Together with the installation guidelines at the end of the chapter, enough information is provided to enable a contractor or skilled individual to install the restraints shown.

Examples of elements that can be mitigated by prescriptive methods include:

- Water heaters, up to 100 gallons capacity
- Suspended acoustic ceilings, up to 4 pounds per square foot in weight

While the underlying design of the prescriptive details has been reviewed by experienced engineers, some judgment is required on the part of the user to ensure that their use is appropriate for the situation. For instance, the ceiling bracing detail shown may not be appropriate for ceilings weighing more than 4 pounds per square foot; the user will need to verify the weight of the ceiling in question.

ENGINEERING REQUIRED (ER) DETAILS

Bracing, anchorage, or restraint details for these components require design by an engineer or design professional experienced in the seismic design of nonstructural elements. The details provided in this document are schematic details showing common solutions for the components in question. These figures do not contain sufficient information for installation; they are provided primarily as an illustration of the required scope of work and the necessary elements for proper seismic restraint. Information regarding the size and spacing of bolts, type and size of steel shapes, appropriate configuration, required restraint capacity, and capacity of the structural elements to which they are attached needs to be determined by an engineer, or in some cases, by a specialty contractor.

The designation Engineering Required has been used for components for which the non-engineered approach is most likely to be ineffective. The recommendation of this guide is that design professionals be retained to evaluate the vulnerability of these components and to design appropriate anchorage or restraint details, particularly when safety is an issue. As stated earlier, this recommendation may apply to all components of specialized facilities such as hospitals and emergency operations or communications centers, where interruption or loss of function is unacceptable. Recent experience has shown many instances in which fire sprinkler and other water lines, HVAC equipment, emergency generators, water tanks, ceilings, parapets, glazing, and such were damaged when subjected to severe shaking and failed to perform as expected. The lesson learned from this experience is that the protection of many items, particularly MEP equipment and architectural components in facilities that are expected to remain functional during and after a major earthquake, is a complex undertaking that should be addressed by engineers and architects with specific expertise in this area. As a result, most MEP systems and architectural components have been given the designation Engineering

Required. Several of the items listed under FF&E and contents have also been given this designation.

The following table lists the subcategories and the component examples included in the following sections:

Table 6.2.1–1 List of Nonstructural Components

Subcategory	Example	Component Type	Type of Detail
SECTION 6.3		ARCHITECTURAL COMPONENTS	
6.3.1		Exterior Wall Components	
	6.3.1.1	Adhered veneer	ER
	6.3.1.2	Anchored veneer	ER
	6.3.1.3	Prefabricated panels	ER
	6.3.1.4	Glazed exterior wall system	ER
	6.3.1.5	Glass Blocks	ER
6.3.2		Interior Partitions	
	6.3.2.1	Heavy	ER
	6.3.2.2	Light	ER
	6.3.2.3	Glazed	ER
6.3.3		Interior Veneers	
	6.3.3.1	Stone and Tile	ER
6.3.4		Ceilings	
	6.3.4.1	Suspended acoustic lay-in tile ceiling systems	PR
	6.3.4.2	Ceilings applied directly to structure	NE
	6.3.4.3	Suspended heavy ceilings	PR
6.3.5		Parapets and Appendages	
	6.3.5.1	Unreinforced masonry parapets	ER
6.3.6		Canopies, Marquees, Signs	
	6.3.6.1	Canopies, marquees, signs	ER
6.3.7		Chimneys and Stacks	
	6.3.7.1	Unreinforced masonry chimney	ER
6.3.8		Stairways	
	6.3.8.1	Stairways	ER
6.3.9		Freestanding Walls and Fences	
	6.3.9.1	Freestanding masonry wall or fence	PR

Subcategory	Example	Component Type	Type of Detail
SECTION 6.4		MECHANICAL, ELECTRICAL, & PLUMBING (MEP) COMPONENTS	
6.4.1		Mechanical Equipment	
	6.4.1.1	Boilers, furnaces, pumps, and chillers (HVAC wet	ER
	6.4.1.2	General manufacturing and process machinery	ER
	6.4.1.3	HVAC equipment with vibration isolation	ER
	6.4.1.4	HVAC equipment without vibration isolation	ER
	6.4.1.5	HVAC equipment suspended in-line with ductwork	ER
	6.4.1.6	Suspended equipment	ER
6.4.2		Storage Tanks and Water Heaters	
	6.4.2.1	Structurally supported tanks and vessels	ER
	6.4.2.2	Flat bottom tanks and vessels	ER
	6.4.2.3	Compressed gas cylinders	NE
	6.4.2.4	Water heaters	PR
6.4.3		Pressure Piping	
	6.4.3.1	Suspended pressure piping	ER
	6.4.3.2	In-line valves and pumps	ER
	6.4.3.3	Flexible connections, expansion joints, and seismic	ER
	6.4.3.4	Pipe risers	ER
	6.4.3.5	Floor-mounted supports	ER
	6.4.3.6	Roof-mounted supports	ER
	6.4.3.7	Wall-mounted supports	ER
	6.4.3.8	Penetrations	ER
6.4.4		Fire Protection Piping	
	6.4.4.1	Suspended fire protection piping	ER
6.4.5		Fluid Piping, not Fire Protection	
	6.4.5.1	Hazardous materials piping	ER
	6.4.5.2	Nonhazardous materials piping	ER
6.4.6		Ductwork	
	6.4.6.1	Suspended ductwork	ER
	6.4.6.2	Air diffusers	NE, ER
6.4.7		Electrical and Communications Equipment	
	6.4.7.1	Control panels, motor control centers, and	ER
	6.4.7.2	Emergency generator	ER
	6.4.7.3	Transformers	ER
	6.4.7.4	Batteries and battery rack	ER

Subcategory	Example	Component Type	Type of Detail
	6.4.7.5	Photovoltaic (PV) power systems	ER
	6.4.7.6	Communications Antennae	ER
6.4.8		Electrical and Communications Distribution	
	6.4.8.1	Electrical raceways, conduit, and cable trays	ER
	6.4.8.2	Electrical distribution panels	ER
6.4.9		Light Fixtures	
	6.4.9.1	Recessed lighting	PR
	6.4.9.2	Surface-mounted lighting	PR
	6.4.9.3	Pendant light fixtures	NE
	6.4.9.4	Heavy light fixtures	NE
6.4.10		Elevators and Escalators	
	6.4.10.1	Hydraulic elevator	ER
	6.4.10.2	Traction elevator	ER
	6.4.10.3	Escalators	ER
6.4.11		Conveyors	
	6.4.11.1	Conveyors	ER
SECTION 6.5		FURNITURE, FIXTURES, & EQUIPMENT (FF&E) COMPONENTS	
6.5.1		Storage racks	
	6.5.1.1	Light duty shelving	NE, ER
	6.5.1.2	Industrial storage racks	ER
6.5.2		Bookcases, Shelving	
	6.5.2.1	Bookshelves	NE
	6.5.2.2	Library and other shelving	ER
6.5.3		Computer and Communication Equipment	
	6.5.3.1	Computer access floors and equipment	ER
	6.5.3.2	Computer and communication racks	NE
	6.5.3.3	Desktop computers and accessories	NE
	6.5.3.4	Televisions and video monitors, wall-mounted	NE
6.5.4		Hazardous materials storage	
	6.5.4.1	Hazardous materials storage	NE
6.5.5		Miscellaneous FF&E	
	6.5.5.1	File cabinets	NE
	6.5.5.2	Demountable partitions	NE
	6.5.5.3	Miscellaneous furniture and fixtures	NE
6.5.6		Miscellaneous Contents	

Subcategory	Example	Component Type	Type of Detail
	6.5.6.1	Shelf-mounted items	NE
	6.5.6.2	Desktop, countertop items	NE
	6.5.6.3	Fragile artwork	NE
	6.5.6.4	Fire extinguisher and cabinet	NE